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Human Ecology
The relationship between humans and the world in which they live.

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Human Ecology

Ronald R. Van Stockum, Jr.

Introduction

"Human Ecology" deals with the relationship between humans and the world in which they live.[1] There is a lack of understanding within the general public about the nature of that relationship. What is generally known is diluted by immersion in a sea of internet information, exploited and inflated to simplicity by politicians, or ignored as irrelevant to the daily pursuit of one's happiness. But scientists, scholars, governmental agencies, and investigative reporters have accumulated and analyzed vast stores of data dealing with our presence on Earth. And we have a history here.

In beginning, it is important to note that the view of human ecology rapidly changes in perspective as one examines it over different time periods and scales of measurement. By examining our experience on a microscopic, genetic, or molecular level, human relationships with this planet are seen in even greater complexity. By studying the fossil record of evolutionary change, one becomes astonished at the progression of life that led to our presence here.

There are more than seven billion people on this planet. Many of Earth's systems are stressed by our presence. Some of these systems, as described herein, are changing in response. The human race is now manipulating its own great genome and seeking to reach out into the solar system, dreaming of future exploration and, undoubtedly, expansion.

But our population's reproduction, expansion, and consumption must be sustainable if humans are to continue to grow and survive on Earth. Our economic structure and its political basis are also part of the mechanisms at work in human ecology. Some of these physical, evolutionary, cultural, and economic systems are discussed in this paper.

Our environment teems with life, both tiny and large–but mostly tiny. Our great bustling and productive population affects the smaller world in massive ways, unnoticed by all but those trained in the observation of minutia. If we adversely affect those vast reservoirs of life, human ecology will necessarily be impacted. Whether those changes will increase human survivability or threaten its existence will play out in time, perhaps more quickly than the great periods of extinctions that are evident in the geologic record of the past. Our record in the geologic strata is being laid down now.[2]

There is a hypothesis postulating that the Earth's systems, both mineral and organic, interact in a relational way so as to form a larger coordinating synthesis. This hypothesis suggests that Earth's combined system is capable of maintaining balanced interactions within the composition of the whole. Such "homeostasis" could define a giant symbiotic relationship, allowing a stable global platform for evolutionary change and species development. Alexander Von Humboldt examined such relationships during his legendary explorations in South America more than 200 years ago.[3] The scientific hypothesis was described in the twentieth century by James Lovelock and heralded by the accomplished cellular biologist Lynn Margulis.[4]

Science has yet to determine that such a global symbiotic relationship between life and this planet, called "Gaia" by Lovelock, actually exists. It may be that all the elements of the Earth's systems act independently of each other except for immediate cause and effects such as those demonstrated in weather patterns. The modern science of climate change and the public concern over global warming are supporting massive data collection and analysis by a new cadre of scientists using the world's most sophisticated computers. We will soon have a better understanding of the complexity of Earth's systems, the interaction between its physical elements, and the relationships of life thereto.[5]

Population

There are more than 7.3 billion people currently alive on planet Earth. As many as 11 billion people will be alive in the year 2100.[6] But the story of human ecology described herein starts not with the larger human organism itself, but necessarily begins with the smallest composition of its parts.

Life evolved on this planet more than 3.5 billion years ago. Perhaps developing first were the self-replicating molecules that found an opportunity to be enclosed within a naturally forming, hollow sphere of phospholipids.[7] These first primitive membranes evolved into "prokaryotic" cells, within which free floating genetic material reproduced itself as the early cell divided. At some point, it is believed that one prokaryotic cell was ingested or invaded by another one, which then developed the ability to survive within the "host" cell. Over time, and multiple evolutionary efforts, both the host and invading cell began to divide and reproduce in unison. They developed a cooperative, mutually beneficial, symbiotic relationship. Thus began a series of changes leading to the development of "eukaryotic" cells, cells with a nucleus that make up the tissues in the animals and plants around us.[8] Our lives developed out of the cooperation between primitive cellular organisms that began as far back as two billion years ago.

Those early eukaryotic cells soon learned to grow together into complex forms. They evolved new, larger combinations of cooperative, multicellular creatures that divided, grew, and reproduced billions of copies of themselves. So it was with humankind. This example of cellular cooperation and evolution by eukaryote cells might prove instructive to humans who now seek to reproduce and maintain even greater populations upon Earth, their "host" planet.

We are descendants, then, of these ancient "chimeras" of combined molecular and cellular life forms. And, on average, each human being is composed of more than 37 trillion of these eukaryotic cells. Humans are much more complex than the body, brain, heart, and large tissues by which they generally describe themselves. Each human is, in reality, a large cooperative group of trillions of cellular life forms.

A great percentage of cells in a human body divide and replace themselves over a lifetime. For example, approximately 40,000 skin cells are lost every minute, a daily replacement of up to 50 million skin cells. And other cells, such as red blood cells and intestinal cells, also reproduce rapidly. Blood cells can travel an average of 1,000 miles a day in our blood stream, being destroyed by the spleen after about 120 days. Some cancer cells, unless destroyed, can replicate indefinitely.

Such is the origin, diversity, and vibrancy of the cellular units that make up our bodies. But each human's combined system is more complex still. Living within or upon each of our bodies are vast armies of microorganisms–bacteria, fungi, and protozoans. Estimates suggest that these microorganisms outnumber the cells of each human body by a factor of ten.[9] And there are over 10,000 different types of organisms that have been identified in the nasal, oral, skin, gastrointestinal, and urogenital areas of the human body.

The Atmosphere

Life on Earth has long interacted with the atmosphere of this planet. Before the evolution of photosynthetic organisms and the release of their waste product, oxygen, the air on Earth had a much different composition. But photosynthesis would dramatically change that composition.

Oxygen is a highly reactive, "mischievous" atom. It is so powerful in its elemental form, O_2, that we describe the burning, destructive principle it embodies as "oxidation," and call it "fire." In the upper atmosphere of Earth, oxygen absorbs the even more destructive energies of solar and cosmic radiation, trapping them into the otherwise unstable bonds of ozone, O_3. Without that protective ozone shield surrounding the planet and absorbing such dangerous radiation, complex life forms would be threatened here, and their further evolution would be compromised.

So it is interesting that free oxygen, the agent of fire, became the mechanism of respiration whereby life would coax work from the photosynthetic reservoir of sugar energy produced by plants. And in a beautiful example of synergy in the consumption of that energy, respiration recycles water and carbon dioxide back into the atmosphere. These ingredients then form the building blocks of more sugar food to be produced by plants through the trapping of sunlight energy in photosynthesis.

Human beings have demonstrated the capability of affecting Earth's atmospheric balance. In the twentieth century, chlorofluorocarbons (CFC) were developed as safe, unreactive chemicals for use in refrigerants and as product propellants. Unknown at first was the tendency of these chemicals to release their chlorine atoms in the upper stratosphere, which then merged with and broke down the protective ozone molecules. The industrial nations of the world quickly recognized the validity of the scientific research investigating this phenomenon. They acted cooperatively to ban or phase out the manufacture and use of such chemicals through the Montreal Protocol of 1989.[10]

There is much to be learned from that successful international effort to protect the ozone. It is especially instructive when considering the current political firestorm over the impact of the release of carbon dioxide to the atmosphere from the burning of fossil fuels.

Energy

Human beings consume energy. They burn fuel in the same way that wood is consumed in a fire, just more slowly and in a controlled fashion. In fact, what we call fire is just energy escaping from the carbon bonds in organic material such as the cellulose in wood.[11] Cellulose is composed of the same carbon-to-carbon simple sugar units that are found in a potato or a grape. Humans, however, do not possess an enzyme capable of breaking out the sugar units from the bonds found in cellulose. Otherwise, the sheet of paper on which you are reading these words would be as edible as a fruit rollup.

Horses and cattle maintain a population of bacteria and protozoa within their guts that do possess such an enzyme. In a classic example of mutually beneficial symbiosis, the protozoans are provided a moist home, with a constant temperature and a continuous stream of plant fiber food upon which to feast. In return, the animals absorb the nutrients released from the plant tissues or produced by the microbes. This is another example of the cooperation of life forms on this planet.

Human ecology is all about energy. Energy that bathes our planet, moves our continents, drives our weather, produces our machines, grows and gathers our food, and fuels our metabolism. In chloroplasts, those tiny manufacturing hubs of photosynthesis, sunlight energy is trapped in the carbon-to-carbon bonds of sugar, fused from the carbon dioxide retrieved from the atmosphere. Those plants trick and trickle the visible wavelengths of sunlight energy into circular metabolic pathways. From there, the plants tease and trap, in manageable quanta, the energies necessary to form the carbon-to-carbon bonds found in the simple sugar, glucose. From the energy in glucose, that most catholic of molecules, all plant tissue is built and all of the consuming animals raised. In death, much of this "organic matter" becomes confined in sediments and covered in layers of geologic detritus. Over time, temperature, and pressure, these sediments become the reservoirs into which we mine and drill to discover and exploit buried reserves of stored organic energy. They are truly "energy warehouses."

We have now found more of these reserves. Much more. Massive quantities of oil and gas are trapped in shale beds of Devonian Age that have only recently become economically extractable by horizontal drilling and "fracking" technologies. And even more buried energy is to be found within the massive oil sands of Alberta, Canada.

Two observations can be drawn from our use of the planet's buried energy resources. One involves the ease of use of these "fossil" fuels and the relatively cheap unit cost to obtain them. That ease can depress the interest and investment in alternative and more sustainable sources of energy such as solar, wind, hydro, geo-thermal, and even nuclear power.

The second involves combustion products released from the use of such fuel. The release of carbon dioxide, toxic metals, and acid rain-forming molecules is of special concern. Coal has drawn special scrutiny, and there are massive worldwide reserves of that compressed organic material available relatively cheaply.

Carbon dioxide is the combustion product of current regulatory focus. Increased carbon dioxide concentrations in the atmosphere can lead to a "greenhouse effect" warming of the planet. For millions of years, significant quantities of carbon dioxide have been removed from the atmosphere by plants whose dead tissues were trapped in geologic strata, their carbon "sequestered" away. That buried carbon would have otherwise influenced the heating up of our atmosphere.

Now, to support the needs and promise of our swelling population, humans are burning more fossil fuels and releasing great quantities of this carbon dioxide "genie" from its geologic repository. If the carbon dioxide released by the burning of fossil fuels results in significantly raised global temperatures, our population and its security could be threatened. Certainly, the numbers and locations where our populations now thrive could be affected.

Water

Water is the stuff of life in this planet. It is the medium in which cells are bathed, and the metabolic vehicle of respiration. In fact, water (H_2O) makes up approximately 60% of the mass of the human body. When its components are broken out on an atomic basis, they account for an even greater percentage: oxygen - 65%, and hydrogen - 10%. Hydrogen is the most abundant atom in the human body and even more so in the universe.

Water is necessary for the operation of animal and plant tissue. In plants, it also provides the turgor for herbaceous tissue to grow upward toward the sun. Without water, plants wilt and lose the ability to transport material through transpiration and evaporation at the leaf surface. In the absence of sufficient water, human cells begin to shrink, blood volume declines, and organs fail. Mental states change, and the human brain eventually drops into a coma.

Although there is plenty of water in the oceans, it contains excessive salt concentrations built up from the erosion of rock surfaces on the surface of the continents. Unlike organisms adapted to live in a sea of salty water, that medium is off limits to humans. In fact, ingestion of salt water exacerbates human thirst and dehydration. For humans, water is truly an alien environment.

So it is ironic that our distant evolutionary origins are in the sea, that the cellular nature of our being is aqueous, and that we are driven by a spiritual and recreational attraction to the seas, lakes, and rivers of the planet. Despite our thirst, water is not unlike the harshness of space, both requiring a "suit" to survive within it.

Even so, our need to tap fresh bodies of water, drain them of their feeding streams, and draw down aquifers, is now some of the most active endeavors of the human species. The reason relates to the places that humans choose to live, and the areas with soil most suitable for agricultural production.

The "carrying capacity" of a land reflects the availability of natural resources needed to support a human population and the attendant agricultural practices necessary to feed it. It cannot be exceeded without enormous expenditures of money and energy to transport in the material necessary to support the population and its activities. So it is with fresh water. This dilemma and its consequences are exemplified by the development of the San Francisco Bay area in California and the expansion of Denver, Colorado.

The San Francisco Bay lies inland of the California coastal mountain ranges where massive redwood trees are soaked by abundant mist and rainfall from the sea. But inside this barrier range of coastal mountains, rain is much sparser, leading into desert conditions farther east in the Great Valley of California. The San Francisco Bay area lacks adequate fresh water resources within its immediate geography to support its population. The city had long lobbied President Theodore Roosevelt to dam up the Yosemite and Hetch-Hetchy Valleys in the Sierra Nevada Mountains and transport the water from those mountains to the city. The flooding of these valleys and the diversion of their rivers was strongly opposed by the famed naturalist, John Muir.

After the great San Francisco earthquake of 1906 and resulting fires, the city prevailed. The Tuolumne River in the Hetch-Hetchy Valley was dammed, and its water transferred to the San Francisco Bay area more than 150 miles away. It is said that the dam broke John Muir's heart, but the powerful environmental group, the Sierra Club, evolved out of the efforts to protect the Sierra Nevada Mountains.[12] If you travel to San Francisco, taste the water. It can be deliciously smooth and pristine.

Denver, Colorado is a metropolitan area serving more than 2.5 million people. It is situated at the base of the tall Front Range of the Rocky Mountains. But as anyone knows who has driven through the Great Plains of America, Denver sits on a prairie at an elevation of almost one mile. The plains around it feather out into grasslands covering the eastern third of Colorado.

Just over that mountainous Front Range to the west, however, lay the headwaters of the mighty Colorado River, with abundant fresh water flowing through the watershed of the Colorado Plateau beyond. The population of Denver, quickly outstripping the fresh water carrying capacity of its location, developed a plan–divert part of the western watershed of the Colorado River east over the mountains. Direct it to supply the growing thirst of the human population and farms around Denver.

This was accomplished in the technologically impressive trans mountain diversion of the "Colorado - Big Thompson Project." Although many dams and reservoirs are involved, the centerpiece is a thirteen-mile tunnel bored under the Rocky Mountain National Park and the Continental Divide. Construction by the U.S. Department of the Interior began in 1937.

In other areas of the United States, municipal and agricultural agencies rely on groundwater accumulated underground over thousands of years. As these sources are depleted, and near surface supplies become exhausted, deeper wells are needed to draw upon the aquifer. As a result, ground subsidence becomes a threat.[13]

Air

It doesn't look real, those pictures from China and India. They show people walking the streets with cloth masks, the air around them swirling in ominous dusty darkness, even in the brightest daylight. Sickening particles, burning acids, and toxic metals are being inhaled with each struggling breath. For the first time in its history, two times in fact, Beijing posted "Red Level" air pollution alerts for the city. That is the highest level of air pollution alert that can be raised for the safety of its citizens.

These surrealistic pictures happened in December 2015, but they are not an unfamiliar sight to persons of the author's generation. These pictures were all too common in America in the 1960s, the price seemingly exacted for the benefits of increased industrial productivity. But America showed the way to deal with the problems of air pollution through the passage of the Clean Air Act in 1970. The United States still leads the world in addressing the ill effects of air pollution.[14]

In 1990, Congress amended the Clean Air Act to more vigorously deal with the release of air toxics.[15] Of greater potential impact is regulation under the Clean Air Act of the release of greenhouse gases related to global warming and climate change. The United States Supreme Court has ruled that EPA has the authority to regulate carbon dioxide (CO_2) as an air pollutant under the authority of the Clean Air Act through an endangerment finding.[16] This was done and, as part of the Obama Administration's program to facilitate international agreements addressing climate change, EPA produced the "Clean Power Plan" on August 3, 2015.[17] This program has engendered a fierce political firestorm with industry representatives and politicians declaring it to be a "War on Coal."

The reliance on relatively inexpensive coal to fuel the industrial progress of the great populous nations of China and India seems, at least in the short run, to be probable. But will those nations be able to enact, enforce, and fund the programs that will control releases of pollutants to the atmosphere? If not, can the health of their population be protected and the potential warming of the planet averted?

Global Warming

Climate change has occurred throughout geologic time. At one time, there was a "Snowball Earth." Numerous glacial epochs have been identified, and periods of high global temperatures have been logged in the geologic record. Many natural phenomena can influence the planet's temperature.[18]

There is abundant agreement within the scientific community concerning the mechanisms of global warming and the role of carbon dioxide (CO_2) therein. Human-induced releases of carbon dioxide are increasing rapidly.[19] Scientists are concerned that the Earth's climate may respond with relatively rapid change. Combined with the impact already evident from a large human population, such abrupt climate change may disrupt the distribution and diversity of life on our planet.

The effect of increasing carbon dioxide levels in the atmosphere has been acknowledged by a great consensus within the scientific community.[20] Meaningful action by international political bodies appears necessary to stave off, or at least address, the consequences of such rising carbon dioxide levels.

The latest international action and cooperative agreement was developed in December 2015 at the Paris, France meetings of parties to the 1992 United Nations Framework Convention on Climate Change. The United States, in preparation for the Paris discussions, submitted its "Intended Nationally Determined Contribution" (INDC) to the United Nations on March 31, 2015. On December 12, 2015, 195 nations agreed in Paris to reduce carbon dioxide emissions by anthropogenic sources so as to limit the further increase of global temperatures to an additional 3.6° F (2° C). One hundred and eighty-six countries, including the United States, had previously submitted CO_2 emission reduction plans.[21] The new Paris agreement, however, lacks the binding mechanism to require such reductions. And $100 billion sought by developing nations to aid in their reduction of CO_2 emissions is only referenced and not promised.

United States President Barack Obama has praised the agreement reached in Paris.[22] The Republican leader of the Senate, Mitch McConnell, opposes such action.[23] Even the Catholic Pope Francis has weighed in on the issue.[24] On February 9, 2012, the United States Supreme Court enacted a "stay" of the effectiveness of the President's "Clean Power Plan," a series of regulations that would reduce the release of CO_2 from electrical generating units by approximately 30% in 2030.[25]

Kentucky has traditionally maintained a significant coal-based component in its economy. But that market has been greatly impacted by the development of large, new reservoirs of relatively inexpensive natural gas, competing as a source of energy for electrical generating utilities. Coupled with economic downturn and increasing governmental regulation of coal combustion emissions, the competitiveness of coal for electrical generation has come under pressure.

It appears, however, that without limitation, the unrestrained release of carbon dioxide from anthropomorphic sources will result in global warming. Destructive climate changes, drought, sea level rises, agricultural disturbances, and diversity loss may be the result.

Planet Change

Much has been highlighted in the press about the potential effects of "Climate Change," but often forgotten is the history of our change to geography. The changes that humans have wrought to their physical environs have been ongoing for so long, reported on so often, and photographed and diagramed so much, that they now seem ordinary. They appear to have been accepted as an undeniable consequence of human progress. But these changes, as beneficial as many are, represent massive changes to the ecosystem within which we live.

Manhattan was once a hilly granite island. It is now a flattened cityscape except for Central Park and Washington Heights.[26] It is home to more than 1.5 million people living within the 23 square miles on the island. That is almost 70,000 people per square mile. During the business day, the population of Manhattan swells to almost 4 million people, nearly 170,000 per square mile. Every weekday, an average of 5.6 million people ride the subway in New York City.

Louisville, Kentucky is another example of physical change within a city. It was once an area of festering swamps, pools of fetid water, and beaver ponds. Phoenix Hill was actually a "hill."[27] The neighborhood of Phoenix Hill is now level and most of Louisville's lowlands have been drained or filled in with whatever was available to level the land.[28]

We have long admired the graceful patterns of elevated rice patty rings encircling the mountains of China, or similar dry farming ridges created by the Incas in Peru. Agriculture can greatly modify the Earth's surface. But some of our larger impacts have involved damming up major rivers, diverting whole watersheds, and mining.

There was great controversy surrounding the impoundment of the Colorado River by the Glen Canyon Dam, which created Lake Powell in Arizona and Utah and formed the second largest manmade lake in the United States. The largest is Lake Mead, impounding the Colorado River by Hoover Dam just downstream of Lake Powell. In fact, there are 15 major dams on the Colorado River, with many more on its tributaries. The capture and withdrawal of water from the Colorado River renders the flow in that river into the Gulf essentially nonexistent.

This pattern is repeated elsewhere in the world. In Iraq, dams, drought, and warfare have been major contributors to the distress and instability of populations along the lower reaches of the Tigris and Euphrates. The Arab "marsh people" have, at various times, found their lands on the lower Tigris and Euphrates Valleys starved of fresh water. As the rivers were dammed or diverted, the wetlands dried up and salt water from the Persian Gulf moved up into their ecosystem and aquifer. Now war has spread into Syria, where revolutionaries control major dams on the Tigris River. The breaching of those dams would create an even greater human tragedy and ecosystem destruction.

Much publicity and litigation has focused on the effects of mountaintop removal for coal mining in Appalachia.[29] Recently, similar outcries have focused on the strip mining of large areas of the Boreal Forest of Alberta in the mining of the vast reserves of oil (bitumen) in its sands.

The impact of mineral mining around the world is large. Colorado in the United States is an example.[30] Copper mines in Peru can encompass areas greater than 125,000 acres with open pits the size of 4 football fields.

Invasive Species and Extinctions

The "Columbian Exchange" is a phrase used to describe the migration of new and old world life forms that followed the European "discovery" of America by Christopher Columbus in 1492. His was just the beginning of many additional voyages of animals and plants crossing oceans that, for millennia, were barriers to movement. Potatoes, corn, tomatoes, squash, sunflowers, chilies, chocolate, and peanuts were exported from their native lands in the New World, while wheat, oats, rye, barley, rice, cabbage, and onions were imported from the Old World.[31] The planet has developed into a displaced mix of life forms often dominating ecosystems foreign to their genome.

Sugarcane, originally native to Asia, was imported to the Caribbean, where it became part of a triangle of trade involving African slaves, Caribbean sugar and New England rum. The massive production and refinement of sugar from sugar cane and sugar beet (the latter native to the Mediterranean and bred in Europe for sugar production) has changed the world.

Turkey was exported from the New World, and chicken imported from India and China.[32] The modern genus of horse evolved in North America approximately three million years ago, but became extinct here approximately 12,000 years ago. However, the horse had previously spread into Eurasia and returned to America along with Columbus. Horses provided superior fighting power to Cortez in conquering the Aztec empire. It was only after the Spanish Conquistador Francisco Vasquez de Coronado invaded New Mexico that horses escaped from his herds to form the basis for the great horse cultures of the Native Americans on the American plains.

Cattle also came to America with the Europeans. In Texas, Europeans on European horses drove European cattle to market. There were no dairies in America until dairy cattle were imported here. There were no potatoes in Ireland when its population was smaller, closer to the carrying capacity of its land. The energy-rich potato allowed the Irish population to explode. All a result of the Columbian Exchange.

Other unseen life forms also migrated. Smallpox, cholera, and typhus, carried by the mostly resistant or immune Europeans, devastated the Native Americans of the New World.[33] It is possible that syphilis developed in America and was responsible for millions of deaths in Europe. It is argued that the long practice of herding cows and sheep in Europe had occurred near large urban population centers with poor sanitation. Exchange of disease organisms between human and animal may have provided the Europeans with greater immunity to disease. Populations in the New World lacked such livestock and urban concentrations, and were especially vulnerable to European diseases.

All of this has occurred against the background of natural variation and selection in the global community of life of which we are part. Although we have discovered many potent antibiotics to prevent disease or to heal its symptoms, as fast as we develop and use those medicines, new organisms evolve resistance to them, making the human population even more susceptible to widespread epidemics of disease.[34] An example is the heavily populated areas of China that live closely with activities of animal husbandry. This situation allows for the rapid development and transmittal of potentially dangerous pathogens between livestock and human species.

The list of devastating human diseases is still long, and new medicines are constantly needed to protect populations from their epidemic outbreaks.[35] For many of these medicines, we still look to our companion life forms on this planet for rescue.

The fossil record shows that the planet changed over geologic time through such mechanisms as volcanic activity, shift of tectonic plates, and even catastrophic collisions with asteroids. Oceans have spread and receded. The fossil record has described at least five major periods of extinction of life on this planet, some tied to these events.[36] There is concern that the impact of human activity is creating a new extinction, reducing the diversity of life as humans encroach upon, alter or destroy Earth's habitats. Some argue that humans may be the cause of a sixth extinction.[37]

In America, the ivory-billed woodpecker and passenger pigeon, magnificent native birds, have disappeared. The species are extinct and lost to the future.[38]

Food and Agriculture

One of the most interesting inquiries of science relates to the nature and lifestyle of the immediate evolutionary ancestors of our human species. How did they live when they left the trees? Why did they adopt an upright bipedal posture? When did they make tools, discover fire and, most importantly, what did they eat? This culinary question is of special interest to both scientists and lifestyle advocates. If we knew, would it be healthier to revert to the foods eaten by our ancestors?

Science is fairly clear that our evolutionary ancestors were opportunistic omnivores, eating both plant- and animal-based foods that they chanced upon. Certainly our teeth indicate that we are generalists. We can bite, tear and grind, but not as well as the carnivore cats or the herbivore horses and elephants.

So it is unlikely that our ancestors ate only meat as suggested in some popular diets. Our ancestors probably ate any small game they could catch, along with grubs and insects, wild fruits and tubers. Our digestive system was developed to accommodate these generally available food sources, and the metabolic processes of liver and cell tuned themselves accordingly. Thus we cannot digest grasses and hay like horses. And only recently have a large population of humans developed the enzyme as adults necessary to digest milk.

One thing appears clear. There were no over-abundant sources of cereal carbohydrates available as a food source before the advent of agriculture. Perhaps this lack of abundant calories, in the form of starch, severely limited the size of our previous populations. Some may have had access to sources of concentrated sugars such as the honey of beehives, but this would have been a distinctly difficult luxury to obtain.

Then humans began a revolution. A revolution in food collection and cultivation. Plants were observed and selectively propagated, producing larger and more nutritious fruits and seeds. Certain animals became domesticated, like the dog, horse, llama, pig, chicken, and cow. How difficult it must have been for the first human who suggested that a family should collect, cultivate, and grow the tiny weedy precursor of wheat. That ambitious suggestion relating to such a small-seeded plant was surely poorly received. But it led to the production of the abundant calories necessary to support the first civilizations of Mesopotamia. And by importing fresh water into an arid land to do it, significant changes to the landscape and ecology began.

That brilliant vision of so much from so little occurred time and time again in human history. In Asia, rice was identified as a source of abundant starch, and supported the development of the largest populations on the planet. In the New World, the tall Mesoamerican weed teosinte was cultivated and bred into our modern corn.

In fact, the most important contribution of Christopher Columbus in sailing to the Americas was arguably the "discovery" of corn and the potato. We have truly become, as were the Native Americans of Central America, "people of the corn." And China now produces more potatoes than any other nation in the world.[39] It is no coincidence that the world's population skyrocketed after the foods of the New World spread across the globe.[40]

And what of the impact of sugar, found in the sweet fruit of the date and fig, and encouraged in the selection of tangy citrus fruits. It was found to be manufactured in marvelous concentrations by the sugar cane, and was bred into higher concentrations in the sugar beet. Refined sugar has come to dominate our processed foods. We have even been able to enhance its taste by increasing the relative concentration in foods of the simple sugar, fructose. In America, it has been suggested that sugar supports an epidemic of obesity.

Genetics

Over the last century, science has pulled back the veil from the most basic structure of the human organism, its genetic code. We have even uncovered some mechanisms regulating the development of the human body. Genes, instructions for the alignment of amino acids in protein enzymes or for the production of other important macromolecules in the cell, are encoded through the association of four types of nitrogenous bases in three adjacent positions (a codon).[41] All of this information is neatly entwined in the deoxyribonucleic acid (DNA) of our chromosomes, coiled up within the nucleus of our eukaryotic cells.

As a result of our research, human ecology now includes exploration within the realm and meaning of our own genetics. It is an inquiry as to our genetic code, structure, and deployment. In it, we seek an aid in the treatment of disease, but the powerful tools that have been developed by geneticists have great potential for manipulation and mischief within the world of life. Those manipulations may create impacts to our planet greater than those that humans have previously wrought by their physical impact.

The development of "genetic engineering" may have started with the selective breeding of plants and animals more than 10,000 years ago. In 1970 came the discovery of site-specific endonucleases called "restriction enzymes." These enzymes allow for specific scissor-like cuts at predetermined areas within a DNA strand. These tools were able to isolate DNA strands with specific genes for study. By the late 1970s, the ability to determine nucleotide sequences was developed; the process became automated in 1987. In 1983, another tool was developed enabling specific regions of chromosomes to be replicated into thousands or millions of copies. This technique, called polymerase chain reaction (PCR), used DNA polymerases and accelerated the cost-effective study of genetics.[42]

Soon enough, the discovery in nature of a number of vehicles for the transfer of bits of genetic material from one organism to another was exploited. Oftentimes, this transfer is accomplished in a virus particle. A gene can "piggyback" upon a virus' genetic material and combine with a host cell's chromosome, enslaving its mechanism of reproduction so as to replicate the foreign gene inserted by the virus. Even electrical fields can create holes in cell membranes to allow passage for foreign genetic sequences.[43]

So, with tools to cut chromosomes in specific areas and the ability to inject specific snippets of chromosome DNA material into host chromosomes, humans can alter the blueprint of life. These techniques have resulted in an explosion of experimentation in many plant and animal species. In some cases, we seek to identify malfunctioning genetic structures that cause disease in humans. But the potential for much more dramatic change in our species is implied in the use of this new technology. It has led into a more focused inquiry into the meaning of life and our responsibility to its natural processes of reproduction. There are groups seeking to prohibit the modification of human genetic structure that can be inherited through sexual reproduction.[44]

Some plants and animals use a dual reproductive strategy that involves both sexual and asexual processes. For the purposes of this discussion, organisms can be considered to have chromosomes in pairs, in what we call a "diploid" condition. If those pairs, and humans have twenty-three such pairs, are to replicate themselves identically, then all of the pairs must be reproduced and passed on to a "daughter" cell. That is similar to what occurs on your skin.

But evolution and natural selection has not drawn humans into this pattern of reproduction for replication of the entire organism. Instead, we use a sexual system that involves halving the chromosomal pairs so that a single member of each pair is passed into a reproductive cell, the "gamete" (an egg or sperm cell). These cells are called "haploid," having only a single set of chromosomes or half of the original number. When one gamete joins with another through insemination in humans, the diploid condition is restored, but with a new mix of chromosomal partners for the pairs. Thus, great genetic diversity is achieved and natural selection has a wider palette from which to draw the future development of our species.

Yet it is known that each cell of an organism contains a full set of chromosomes with all of the information necessary to reproduce the entire organism. As cells develop into tissues, those portions of the chromosomes not dealing with those tissues' functions are turned off. In theory, if they could be reset, each cell could give rise to any other tissue in the organism. Originally a concept of science fiction, the process is referred to as "cloning." This potential has now moved into the realm of reality in the cloning of organisms as sophisticated as a sheep.[45]

Understanding cloning requires the recognition that cells, during development after fertilization, selectively turn on and turn off chromosomes to express the kinds of cells that are developing within the organism. These original cells are often referred to as "stem cells" and, in theory, have the capability of developing in any direction, into any tissue of the organism.

These new techniques of genetic engineering will only become more widespread and successful in their application. Humans will be hardly restrained in the manipulation of the ecology of their own chromosomes. Combined with genetically modified plants and animals, the potential of impacting our world and the humans within it becomes great. How these new developments will affect human society, and that society with the environment in which we live, has yet to be determined. But surely the potential of that impact is great.

Large agrichemical and biotechnology firms have long been editing plant chromosomes to produce more productive crop yields. They have incorporated resistance to herbicides that kill off competing weeds but not the crop itself. This has resulted in the advent of widespread "no-till" agriculture, eliminating the plowing and the resultant topsoil loss to erosion. An international furor has ensued, however, over the consumption of these genetically modified organisms (GMO) and the increased use of herbicides.

Space

Human ecology now reaches out beyond our planet.[46] After the Soviet Union launched Sputnik 1 in 1957, a great political urgency developed in America to reach the moon first. Americans were successful, landing humans on the moon six times between 1969 and 1972. Numerous specimens of its surface were returned to Earth and scientific experiments undertaken. However, after that initial flurry of exploration, humans, assessing the cost, seemed to lose interest and have not returned.

Yet popular interest has not waned, and has now expanded beyond the moon. The imagination of the world is fueled by science fiction writers and the entertainment industry. More and better data is being returned by our unmanned spacecraft seeking to find evidence of life in the solar system beyond that on our planet Earth.

The general public is now greatly focused on the planet Mars, which lies 249 million miles away from Earth and is the fourth planet out from the sun. Mars has been considered as another possible location for the evolution of life in the solar system. This is possible because our unmanned spacecraft, landers, and rovers have demonstrated that there is water on Mars. And it is likely that, in the great past, there was running water on the surface of Mars sufficient to sculpt the landscape.[47]

Humans are people of water. Literally. Where there is water, there may be life processes similar to those on Earth, even if exceptionally primitive. Although the debate about traveling to Mars and living there generates much enthusiasm, such long-term occupation would require the "terraforming" of Mars.[48] Human survival on Mars has recently been the subject of a popular Oscar-nominated movie about a stranded astronaut forced to survive on that planet.[49]

It is always water that we seek in our probes, and scientists are always excited to learn that this simple molecule is present in either a liquid, gaseous, or more often, frozen form in our solar system. Far, far away, orbiting the planet Saturn, there is an icy moon called Enceladus. It appears to harbor liquid water in an ocean under a frozen crust. If so, might we also find life forms that far away from the sun?

Our fixation with water has even driven us to inquire where the water came from that is found on planet Earth. There are many hypotheses about how water formed here in its abundant liquid form. An intriguing analysis of water on comets now leads us to believe that it was not deposited through early comet collisions during the formation of the solar system.

Along with water, we seek that "stuff of life," those organic molecules that we once hypothesized were originally formed on this planet through the interaction of electrical storms on a "primordial soup" of chemicals. We have discovered, however, that organic compounds can be found throughout the cosmos. And the building blocks of life, or the early life forms themselves, may have been transported to our planet from matter ejected from other planets that have been struck by planetoids. In some meteorites that land on Earth, traces of organic compounds have been identified. Likewise, organic matter has been found on comets that visit our solar system.

So is it possible that there is still life on Mars? There is evidence of water there now, and canyons and slopes carved by water in the ancient past. Any life forms would most probably be extinct or have been driven underground after the loss of the Martian atmosphere billions of years ago. But may ejecta from the "red planet" have populated our planet with the beginnings of its own organic trajectory? Perhaps the reverse is true, and any life on Mars could have started from material ejected from Planet Earth. And contamination on our spacecraft may possibly have already brought some of Earth's organic compounds to these other planets as "hitch-hikers."[50] These are intriguing questions.

It is an accepted characteristic of our species to wonder about all things, and to seek out knowledge through discovery. Our species has even reached out beyond the solar system into the recesses of deep "outer space" itself. It is an ambitious undertaking.

The 1972 and 1973 Pioneer 10 and 11 spacecraft contained a plaque describing human beings and the location of our planet. In 1977, the two Voyager spacecraft carried a "Golden Record" with even more information about our species and Earth's location.[51] In fact, Voyager 1 has now escaped the restraints of the sun and is traveling beyond the "heliosphere" into the absence we call "outer space."[52]

We know very little about the ecology of the universe. In fact, we know very little about what we call "matter" in the universe. It appears that the relationship that we have with the material that we recognize as matter represents only a tiny fraction of that which exists in the universe. Most of the matter in the universe seems to be "dark matter," and we have yet been able to demonstrate its presence. There is much more to discover.

Conclusion

Nothing exists entirely on its own.[53] As we learn more, everything on this planet appears to be more related, interacting at different levels of complexity to form the world in which we live. Human actions can change those relationships, and change the world in ways that decrease its capabilities to absorb the impacts of our burgeoning population. As a single species, we can overpower the ability of the air, water, and soil around us to accommodate our wastes. We can cause acute and chronic disease in our people. We can alter our planetary protective "ozone" shield, drain our freshwater aquifers, and deplete the natural diversity and genetic reservoir of life that existed on the planet Earth before we came to dominate it. We can trigger massive climatic shifts by altering small percentages of greenhouse gases released to the environment. We can over-populate the Earth, at least in those areas that lack the capacity to support us.

Perhaps much more growth in the human population on this planet can be expected, sustained, and would be welcome. The quality of the lives thus living, however, will be determined by the relationship with everything around them, and not just by the cultural philosophy of society. Understanding that relationship, and acting to protect and preserve it, surely gives the human population the greatest opportunity to grow, reproduce, and be productive.

Without a better understanding of the world in which we live and our impact on it, perhaps we risk changing it in ways that limit, or even threaten, the health of our population. Perhaps to continue unrestrained on a course of unlimited growth and consumption is unwise without a better understanding of the effects of such actions on the related planetary systems of Earth.

We are only now beginning to understand these dynamics. The choices that are made by the various peoples and nations of the world as we do so, may very well dictate the future of our human ecology.

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References

1 The term "human ecology" is described by the 1970 edition of the Encyclopedia Britannica, as the "... study of man's collective interaction with his environment. Influenced by the work of biologists on the interaction of organisms within their environments, social scientists undertook to study human groups in a similar way ... Human ecology views the biological, environmental, demographic, and technical conditions of life of any people as an interrelated series of determinants of form and function in human cultures and social systems. It recognizes that group

behavior is dependent on resources and associated skills and upon the body of emotionally charged beliefs; these together give rise to a system of social structures."

2 The 1933 Oxford English Dictionary (1988 compact edition of the OED, four pages reduced and printed on one) has no entry for the word "ecology." The closest entry is for the word "eclogue" for which it gives one description as "a short poem of any kind, especially a pastoral dialogue, such as Virgil's bucolics." The word "human" is referenced in the Oxford English Dictionary as " ... belonging to man, human, a derivative of the same as root as homo ..." Note that originally the stress was on the last syllable of "human." It switched to the beginning syllable in accordance with English usage. The dictionary cites a 1398 quote as follows: "This creatour thenne made man, and nature humayne comune."

3 The great explorer and naturalist Alexander von Humboldt (1769-1859) suggested that a cooperative relationship existed between the elements of nature that he observed. He described the world, "... as a natural whole animated and moved by inward forces ..." and stating, "In this great chain of causes and effects ... no single fact can be considered in isolation."

4 "Gaia, a single enormous system deriving from common ancestors at least 3,500 million years old, is connected through time (by ancestry) and space (through atmosphere chemical signals, ocean currents and the like); the Gaian system persists in the face of changes (population expansions and extinction, sea-level changes and so forth). Variations in the ability of organisms to inject their genes into the next generation are one such change." Lynn Margulis and John F. Stolz, Scientific American, Letter to the Editor, March, 1990.

5 Early photosynthetic life forms changed the planet's atmosphere by releasing massive amounts of free oxygen 2.5 billion years ago. That free oxygen allowed for an explosion of growth by life forms using respiration to release energy trapped in the photosynthetic plant product, glucose. More importantly, it created an ozone barrier protecting life from harmful solar and cosmic radiation and allowing it to evolve to more complex forms of life. The interaction between life and atmosphere continues today.

6 Patrick Gerland et al., World Population Stabilization Unlikely This Century, Science, Vol. 346, Issue 6206, PP. 234-237, October 10, 2014; Although it is impossible to accurately determine the total number of human beings that have lived on Earth throughout time, a reasoned exercise in speculation is informative. One investigator calculated that more than 106 billion human beings have lived on this planet, 6.5% of which are alive today. (Population Reference Bureau, 2011).

7 An example of such phospholipid is the lecithin molecule, found in numerous plant and animal tissues and famously in egg yolk. The molecule's phosphate "head" exhibits a charge that is attracted by the polar covalent bonds in water molecules. A long neutral hydrocarbon "tail" attracts oil, repelling water. Mixed with water, lecithin associates to form naturally hollow spheres with the charged heads facing outward and the neutral fatty "tails" focused inward. Lecithin is what allows vinegar and oil to form a stable mixture in mayonnaise. Fatty acids broken free from fats and oil by the use of lye are similarly charged. One end has a charge that mixes in water, and the other being neutral, mixes with oil. Hand soap is formed from such fatty acids.

8 Lynn Margulis was a proponent of the theory of "Endosymbiosis." In this theory, the presence of mitochondria (the respiration, energy releasing organelle), and the chloroplasts (the photosynthetic, glucose-producing organelle), were originally free-living prokaryotic cells. They became either prey or parasite to another prokaryotic cell and eventually developed a mutually beneficial symbiotic relationship. Now these fully integrated organelles reproduce upon receiving instructions from the nucleus to do so. They can no longer live alone outside the cell. The nucleus itself may have a similar origin, or possibly represents an enfolding of the cell membrane.

9 A new analysis, however, challenges that conclusion and suggests that the ratio of bacteria to human cells may actually be 1 to 1. Are We Really Vastly Outnumbered? Revisiting the Ratio of Bacterial to Host Cells in Humans, Sender et al., Cell, Vol. 164, Issue 3, Pgs. 337-340. (January 28, 2010).

10 The Montreal Protocol on Substances that Deplete the Ozone Layer, was effective on January 1, 1989. It has led to the reduction or elimination of almost 100 ozone depleting chemicals. All members of the United Nations (197) are signators to the agreement.

11 Humans describe the use of energy in different ways. In food, we use Kilocalories (1,000 small calories) but call them calories (kcals). Check out any food label. Here is what it means. There are 4.2 joules (international unit of energy) in each small calorie. A small calorie is the energy needed to raise the temperature of water 1.8° F (1° C). Burning glucose releases about 680 kcals of energy per gram of molecular weight, of which respiration retrieves 37-50% and traps in the phosphate bonds of adenosine triphosphate (ATP). So for each sugar molecule (glucose), a net of 36 ATP is produced. About 8.8 ounces of your body weight at any one time is in ATP and represents about the energy in one "AA" battery. But every day you will convert and recycle your body weight in ATP. One alkaline-based "AA" battery contains about 9360 joules (or 2.2 kcal equivalents).

12 The Sierra Club website in its History Page recites a John Muir quote from his 1912 book, *The Yosemite*. "Everybody needs beauty as well as bread, places to play in and pray in, where nature may heal and give strength to body and soul alike."

13 One of the most shocking examples of land subsidence is found within the Great Valley (San Joaquin Valley) of

California. It is also significant in areas such as Denver, Colorado; Atlantic City, New Jersey; and Baton Rouge and New Orleans, Louisiana.

14 In 1970 during the Republican Administration of Richard Nixon, the United States Congress enacted the Clean Air Act, which would become the model of "Command and Control" environmental statutes. The new law found, "that the growth in the amount and complexity of air pollution brought about by urbanization, industrial development, and the increasing use of motor vehicles, has resulted in mounting dangers to the public health and welfare, including injury to agricultural crops and livestock, damage to and the deterioration of property, and hazards to air and ground transportation." The Environmental Protection Agency (EPA) was formed and quickly addressed control of six pollutants; lead (P_b), ground-level ozone (O_3), carbon monoxide (CO), particulate patter (PM), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). EPA later established a program to control acid rain by products of electrical generating units.

15 Prior to 1990, EPA had only regulated seven hazardous air pollutants. The 1990 amendments required EPA to regulate a specific list of 187 more chemicals including volatile organic compounds (VOCs), metals, inorganic chemicals, semi-volatile organic chemicals, polycyclic organic matter (POM) and poly nuclear aromatic hydrocarbons (PAH). This is of special interest in Kentucky where the airborne deposition of mercury causes warnings about consumption of fish caught in Kentucky waters. EPA's regulation of mercury and air toxics continues to be litigated before the nation's highest courts.

16 To review the Supreme Court Decision, see Massachusetts v. EPA, 549 U.S. 497 (April, 2007).

17 The Obama Administration published the "Clean Power Plan" on October 23, 2015 (Federal Register, Vol., 80, No. 205, Pgs. 64662 et seq.). The Plan seeks to significantly reduce CO_2 emissions from existing fossil fuel-fired electric generating units (EGUs). On February 9, 2016, the United States Supreme Court ordered a Stay on its application, pending review in Federal Court.

18 There are a number of factors that can affect climate change in addition to the release of greenhouse gases to the atmosphere. They include orbital forcing through the Milankovitch cycles of obliquity, eccentricity, and precession; soot; solar storms; volcanoes (aerosols and particulate matter); ocean circulation including the Atlantic Meridional Overturning Circulation (AMOC) and the North Atlantic Oscillation (NAO); El Nino; mountain building; and asteroid impact.

19 Intergovernmental Panel on Climate Change (IPCC), 2013, states: "The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification."

20 What We Know: The Reality, Risks, and Response to Climate Change, 2014, The American Association for the Advancement of Science (AAAS), states: "The evidence is overwhelming: levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse as is extreme precipitation. The oceans are acidifying."

21 Germany has determined to reduce greenhouse gas emissions through its Energy Transition Program, "Energiewende." The country's goal is to achieve an 80-95% reduction by 2050, abandoning coal for renewable sources such as ocean power. Germany also plans to shutter its seven nuclear plants by 2022. Currently, Germany leads European nations in greenhouse gas emissions, with coal accounting for 40% of that release.

22 On December 12, 2015, United States President Barack Obama stated, in part, as follows: "Moreover, the Agreement sends a powerful signal that the world is fully committed to a low-carbon future ... So I believe this moment can be a turning point for the world..."

23 Mitch McConnell (R-Ky), Senate Majority Leader, stated, "Before his international partners pop the champagne, they should remember that this is an unattainable deal based on a domestic energy plan that is likely illegal, that half the states have sued to halt, and that Congress has already voted to reject."

24 In 2015, Catholic Pope Francis released an encyclical, "On Care For Our Common Home." Selected subtitles of the encyclical are of interest: "Pollution and climate change;" "The issue of water;" "The loss of biodiversity;" "The mystery of the universe;" "The message of each creature in the harmony of creation;" "The crisis and effects of modern anthropocentrism;" "New biological technologies;" "Integral ecology;" "Environmental, economic and social ecology;" and "Beyond the sun."

25 See 40 CFR Part 60, "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units; Final Rule," Federal Register, Volume 80, No. 205, Pgs. 64662 et seq., October 23, 2015.

26 In comparison, examine the cities of Rome or Cincinnati where hills make up the challenge, charm and history of the places.

27 The Highlands around Louisville remain. They are part of a "cuesta," a one-sided escarpment or slope rising to the surface of an upper plain. In this case, the land rises from the Ohio River floodplain to the limestone plateau of the Outer Bluegrass Region. There were also Native American mounds, now leveled, in Louisville.

28 Louisville is famous for the Falls of the Ohio, a long cascading series of rapids forming the only navigational barrier on the Ohio River. The reason for these rapids is the river cutting into Devonian Age fossil reefs. It is one of the world's greatest outcrops of this age. It contains the same fossils that wash up on the shores of Lake Michigan and are prized today by collectors as "Petoskey Stones."

29 See, "Deep Impact: Effects of Mountaintop Mining on Surface Topography, Bedrock Structure, and Downstream Waters," Matthew Ross et al., Environmental Science and Technology, January 22, 2016.

30 In 2015, approximately 3 million gallons of toxic sludge waste was released to the Animas River from the Gold King Mine in Colorado. The mine had been abandoned in 1923.

31 Our foods have an interesting origin. Bananas arose in New Guinea, and the orange from East Asia. Coffee arose in Ethiopia, and the apple from Central Asia. The pineapple is from the Amazon, and the avocado from Central America.

32 The Thanksgiving turkey, a fowl native to the Americas, averaged 16.8 pounds in 1960. In 2015, it weighed greater than 30 pounds. Compare this to the change in human weights. In 1960, human males in America averaged 166 pounds. In 2015, the average was 195.5 pounds.

33 The Jemez people in Northern New Mexico are descendants of the great efflorescence of Pueblo people in the area of the Jemez Mountains west of Santé Fe. Originally numbering as many as 8,000 members, a recent study suggested that greater than 80% of the population had died 100 years after European contact in 1541. It is presumed that they died during epidemics of European diseases such as smallpox, typhus, and measles. One effect of this dramatic depopulation was an increase of catastrophic fires in the surrounding forest. A single village, the Jemez Pueblo, houses approximately 2,000 of the Jemez people. The Pueblo is closed to the public.

34 The World Health Organization lists the following pandemic and epidemic diseases: 1) avian influenza; 2) cholera; 3) coronaviruses (mers, sars); 4) hendra virus; 5) influenza; 6) leptospirosis; 7) meningitis; 8) nipah virus; 8) plague; 9) Rift Valley fever; 10) smallpox and human monkeypox; 11) tularemia; 12) viral hemorrhagic fevers (ebola, Marburg, Lassa, Crimean-Congo, etc.); 13) yellow fever; and 14) zika virus.

35 The zika virus is a member of a group of viruses that cause dengue, yellow fever, and West Nile disease. It had previously been known from Africa and Southeast Asia in a handful of mild cases. In 2007, it exploded into the Pacific Islands, crossing over to Brazil. There, large populations of the virus' mosquito vector, Aedes aegypti (Yellow Fever Mosquito) and Aedes albopictus (Asian Tiger Mosquito) exist. The virus is new to the Americas so little immunity exists here. The mosquitos range over only several hundred yards, so infected humans extend the spread in the range of the virus. The mosquito species are also present in the Southern and Eastern United States. There is currently no vaccine for the virus and no drug to counteract its effects.

36 At least five extinctions are reflected in the geologic record of Earth: 1) Ordovician Extinction (443 mybp), fluctuating seas, increased atmospheric carbon dioxide, reduced oxygen in the atmosphere. 80% of species extinct; 2) Late Devonian Extinction (359 mybp), a period of global cooling where atmospheric carbon dioxide and oxygen are reduced. 75% extinction; 3) Late Permian Extinction (251 mybp), volcanic action releases clouds of sulfur dioxide and carbon dioxide. Acid rain occurs during a period of global warming and ocean acidification. 96% extinction; 4) Early Triassic Extinction (200 mybp), volcanic activity increases carbon dioxide and sulfur dioxide in the atmosphere, ocean acidification and global warming. 80% extinction; 5) Late Cretaceous Extinction (65 mybp), volcanic activity and asteroid impact, increased carbon dioxide levels and reduced oxygen levels, atmospheric heating and abrupt cooling. 76% extinction; (HHMI).

37 The Sixth Extinction, An Unnatural History, Elizabeth Kolbert, 2014, Henry Holt and Company.

38 At 1:00 AM on the morning of Tuesday, September 1, 1914, "Martha," the last living passenger pigeon, Ectopistes migratorius, died at the Cincinnati Zoo. In 1860, one flock of perhaps 3.5 billion birds was described as follows: "Early in the morning ... I was perfectly amazed to behold the air filled, the sun obscured by millions of pigeons ... in a vast mass a mile or more in breadth, and stretching before and behind as far as the eye could reach ... It was late afternoon before any decrease in the mass was perceptible, ... the column could not have been less than three hundred miles in length."

39 Potatoes originated in South America. In 2012, Americans consumed 27 pounds of fresh potato products, down from 47 pounds in 1970. In 2012, the potato crop was worth $4 billion and potato chips or chip products sold for $7.5 billion.

40 There are 90 million acres of corn grown annually in the United States. In 2014, the average yield of American corn was 171 bushels per acre, with each bushel weighing 56 pounds. Each pound yields an average of 1,566 calories. That is approximately 15 million calories for each acre of field corn. The 2014 corn harvest in America totaled approximately 14 billion bushels. Humans burn about one million calories a year. 14 billion bushels of corn can feed more than 15% of the world. Wheat grows about 4 million calories per acre and soybeans, 6 million. Rice comes in at 11 million calories per acre with potatoes rivaling corn at 15 million calories per acre. For comparison, broccoli produces only 2.5 million, and spinach 2 million calories per acre.

41 There are actually five nitrogenous bases. Adenine, guanine, cytosine, and thymine are found in DNA. Uracil substitutes for thymine in RNA.

42 The effectiveness of PCR was greatly enhanced by the discovery of the TAQ polymerase, which operates at high temperatures greater than 113° F. It was found in a thermophilic bacterium, Thermus aquaticus, isolated from the hot springs in Yellowstone National Park. This prokaryotic organism is a heterotrophic bacterium feeding on organic material in its hot milieu.

43 In 2012, a new mechanism for genetic editing was developed. This process is called CRISPR (clustered regularly-interspaced short palindromic repeats) and takes advantage of a bacterial process that aids in the buildup of acquired immunity in bacteria. In association with DNA endonuclease and guiding RNA (CAS9 or CRISPR-associated protein nine), CRISPR can suppress genetic function or insert foreign DNA sequences in a chromosome.

44 In February 1975, a conference was held at the Asilomar State Beach Conference Center near Monterey, California. The conference dealt with the potential risks attendant to new genetic engineering technologies. The National Institutes of Health published guidelines on the subject in 1976. Current guidelines are entitled "NIH Guidelines For Research Involving Recombinant or Synthetic Nucleic Acid Molecules" (November 2013). See amendments in the November 6, 2013 Federal Register (78 F.R. 66751). The British government recently approved the altering of DNA in human embryos during the first seven days of development into the 300-cell blastula.

45 Dolly was a domestic sheep that was cloned from a single adult somatic cell. She was born in 1996 and lived for seventeen years. In the process of developing Dolly, a surrogate mother carried the nucleus of another sheep's cell, that had been removed and inserted into a third sheep's cell. This combination cell was caused to begin its division by an electric shock.

46 Television explored this issue with early science fiction serials produced in Britain. "Target Luna" aired in 1960 and "Pathfinders to Venus" in late 1960 and 1961. These shows were produced by Sydney Newman who would gain fame as the producer of the British Broadcasting Company (BBC) serials, "The Avengers" (1961-1969) and "Dr. Who" (1963 through the present and twelve doctors).

47 The British Broadcasting Company dealt with the concept of life on Mars in the context of the Cold War. In the serial entitled "Quartermass and The Pit," written by Nigel Kneale and broadcast in six episodes in 1958, Andre Morell, as Professor of Quartermass, concludes with the following statement: "For they have outgrown the Martian in us ... and the ancient destructive urges in us grows more deadly as our populations increase and approach in size and complexity of those of ancient Mars. Every war crises, witch-hunt, race riot, purge, is a reminder and a warning. We are the Martians. If we cannot control the inheritance within us, this will be their second dead planet." Even President Ronald Reagan was enamored with imaginative life on Mars. As a young lifeguard, he was fond of reading the Edgar Rice Burroughs series about John Carter and "The Princess of Mars."

48 Mars is not a hospitable place for life, as we know it. Although it appears to once have had a more significant atmosphere, that atmosphere was literally "blown away" by the violence of the solar wind. That wind also impacts Earth but our planet projects a protective magnetic sphere that deflects the sun's particles around our planet. Mars has no such protective shield. Furthermore, life on Earth released enough free oxygen 2.5 billion years ago to form a protective ozone layer intercepting cosmic and solar radiation injurious to our cellular reproductive processes. Although Mars once had enough surface water to carve canyons, water is now locked in a CO_2 matrix of permafrost, or hidden underground, and the ozone layer, if it ever formed, escaped into space long ago. Without a magnetic shield and protective ozone layer, human life would be at risk on Mars.

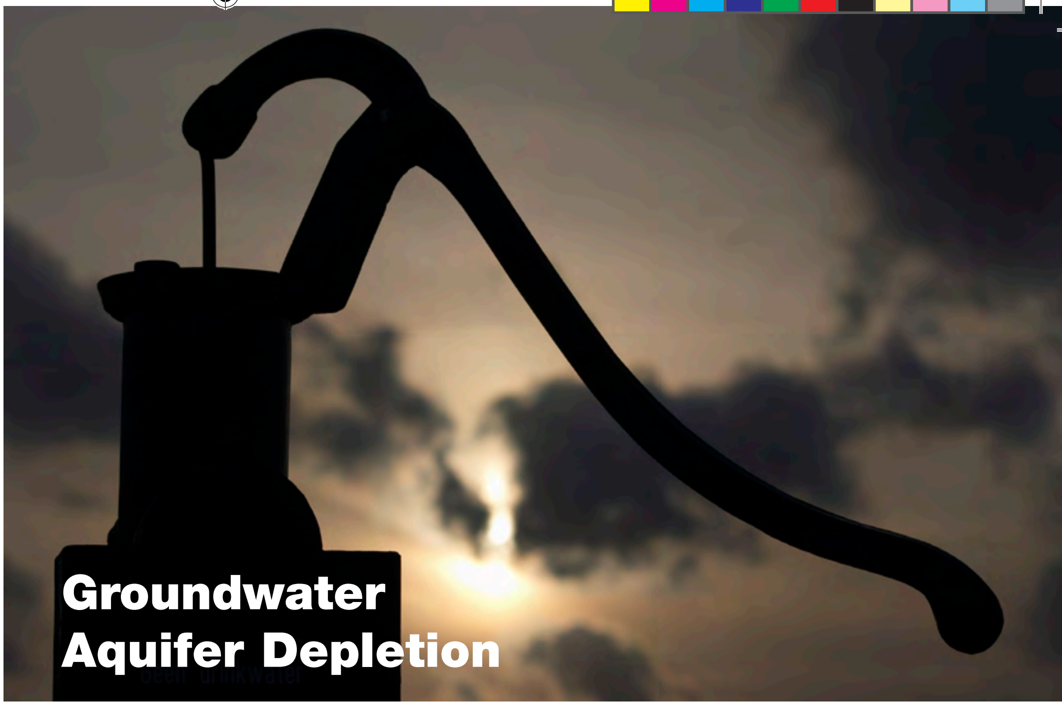
49 There have been many serious, comedic, and campy movies about Mars. They include: 1) The Martian (2015, Matt Damon, nominated for six Oscars in 2016, including Best Picture and Best Actor); 2) Mars Attacks (1996, Tim Burton); 3) John Carter (2012, Andrew Stanton); 4) War of the Worlds (1953, by Ron Haskin); 5) Mission to Mars (2000, Brian de Palma); 6) Abbott and Costello Go to Mars (1953); and 7) Total Recall (1990, Paul Verhoeven).

50 The Outer Space Treaty was ratified by major international nations in 1967. As part of its terms, a Committee on Space Research (COSPAR) works to seek protection from planetary contamination through spacecraft travel.

51 The 1972 Pioneer 10 and 1973 Pioneer 11 spacecraft carried a 6' x 9' plaque attached to its antennae support. The plaque shows a diagram of two naked humans, male and female, not holding hands. The plaque also gives the location of the sun and planets of the solar system. The two Voyager spacecraft launched in 1977 contain a 12" "Golden Record," which details life on Earth. The cover of the record has etched upon it instructions on how to play the record, and more instructions on finding Earth.

52 One wonders, if there is other life in the universe, whether we should be presenting a roadmap to our home planet.

53 Various religious systems support a God that is separate from the created universe, while others find the presence of God in all things. For an example of biblical language on the subject, see the so-called "dominion clause" in Genesis 1:26, 28: "And God said, let us make man in our image, after our likeness; and let them have dominion of the fish of the sea, and over the fowl of the air, and over the cattle, and over all of the Earth, and over every creeping thing that creepeth upon the Earth ... and God blessed them, and God said to them, be fruitful, and multiply, and replenish the Earth, and subdue it; and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth on the Earth." Some argue that this provision has defined the approach of western civilizations to the environment in which we live.



Groundwater Aquifer Depletion

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Introduction

This paper is about groundwater, the fresh water that exists within the pore spaces of underground aquifers. Groundwater stored in underground aquifers has been tapped by shallow wells and used as a water source for thousands of years. However, with the advent of modern drilling technology and gas-powered pumps, the magnitude of groundwater exploitation around the world has greatly increased. As more easily accessible surface water resources have become damaged or overused, humans have increasingly turned to groundwater to support life and our life-styles on earth. As a consequence, in many parts of the world, important groundwater aquifers are becoming depleted.

Groundwater depletion occurs when, on average and over the long-term, the rate of groundwater extracted by humans exceeds the rate of groundwater captured by an aquifer, which is defined as aquifer recharge minus natural discharge. Aquifer recharge occurs when precipitation, whether falling as rain or snow, infiltrates below plant root zones and percolates to the water table within an aquifer. Natural discharge occurs when groundwater, after slowly migrating through the aquifer, discharges at topographic low spots such as rivers, lakes, and oceans. Thus, the difference between aquifer recharge and natural discharge determines whether an aquifer is naturally gaining or losing groundwater, in the absence of groundwater extraction by humans.

Groundwater depletion is a long-term decreasing trend in the amount of groundwater stored within an aquifer system, and is primarily identified by a lowering of the water levels in wells penetrating the aquifer. Under normal conditions aquifer systems exhibit water level changes over time due to variations in the inflows to and outflows from the system. For example, in many groundwater basins in the western United States, pumping for irrigation during the dry summer months typically causes a drop in groundwater levels, which then recover (i.e., rise) during the following rainy season. These short-term declines in groundwater levels and storage related to normal pumping cycles or climatic variability do not themselves constitute groundwater depletion. Only when the trend persists over the long-term (e.g., decades) and over periods of normal climate is the trend indicative of aquifer overdraft and depletion.

Globally, groundwater aquifer depletion is occurring in response to the demands of an ever-increasing global population, currently estimated at approximately 7.3 billion people and forecast to grow to approximately 11 billion by the year 2100 (United Nations, 2015). Although fertility rates have fallen in many parts of the world, human population may continue to increase thereafter (Gerland and others, 2014). In developing countries experiencing rapid economic expansion and increases in standards of living (e.g., Brazil, Russia, India, Indonesia, China, and South Africa), water consumption is rising at a rate even faster than can be attributed to population growth alone (OECD, 2015). A significant component of this increasing per capita demand is due to a shift towards non-vegetarian diets, with higher water content per caloric unit compared to plant-based diets and therefore greater water use per capita for food (Giovannucci, 2012; Gleick and Mercer, 2008). As a result of such pressures, the rate of global groundwater depletion in the year 2000 was estimated at 283 (+/-40) km^3/yr, up from 125 (+/-32) km^3/yr in 1960 (Wada et al., 2010).

Global water demand is predicted to increase substantially in the near future. UNESCO (2015) projects that by 2050, global water demand will increase by 55 percent, primarily due to increased demands from manufacturing, thermal electricity generation and domestic use. By 2050, agriculture will need to produce 60 percent more food globally, with 100 percent more required in developing countries. So where will this water come from? For many parts of the world there are no easy answers.

Groundwater depletion, of course, is not distributed uniformly around the planet, but is more acute in areas where the ratio of groundwater demand to supply is the greatest, i.e., areas with high overlying population densities, lower and more sporadic precipitation, or both. Such areas include the deserts of the Middle East, North Africa, and North America as well as regions with "Mediterranean" climates characterized by dry summers and wet winters such as parts of California, Australia, and South Africa. Whereas groundwater resources in these areas

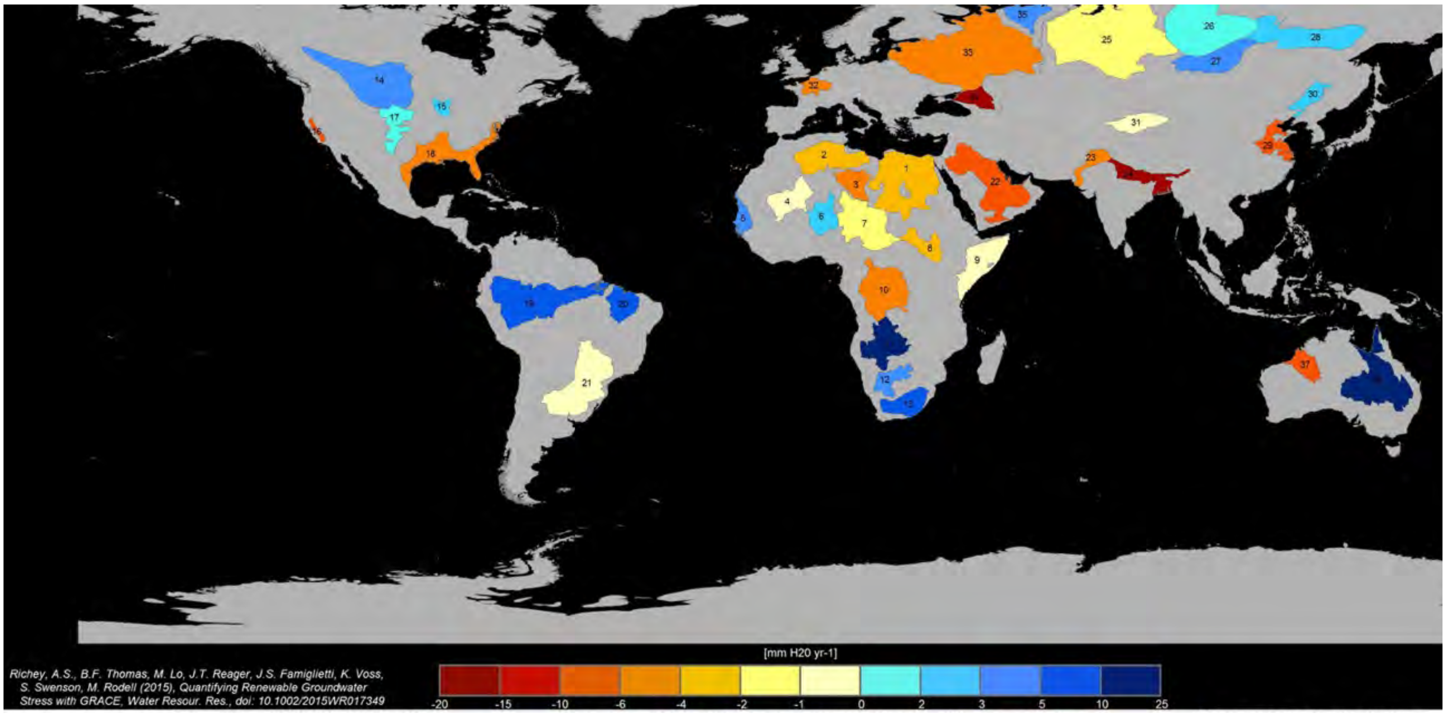

Figure 1 – Trends in Groundwater Storage (millimeters of water per year) from NASA GRACE Mission (2003 – 2013) from Richey and others (2015). Credit: Graphic from NASA Jet Propulsion Laboratory

could have perhaps supported the lower populations of the past, they are showing signs of stress under today's conditions of increased demand.

Understanding where aquifer depletion is occurring is a key step in assessing the extent to which these water resources will be available in the future. Unfortunately, data on groundwater conditions are often difficult to obtain or compile in a systematic way, especially in poorer or more sparsely populated areas. To overcome this difficulty, researchers, including several NASA scientists, have recently conducted studies of the earth's 37 major aquifer systems using data from space-born gravity sensors [i.e., the Gravity Recovery and Climate Experiment (GRACE)], to assess the extent to which each system is stressed (Richey and others, 2015) (Figure 1). The GRACE study involves the novel use of gravity sensors to detect small changes in the gravitational field of the earth, variations that are attributed to changes, over time, in the mass of water stored as groundwater, thus allowing estimation of the rate of change of groundwater storage. Coupled with estimates of groundwater use, the storage change estimates were used to classify each aquifer on a scale of stress ranging from unstressed to variable stress to overstressed. According to the analysis of GRACE data, 8 aquifers are "overstressed" and are being depleted, 13 are "variably stressed", and 13 are "unstressed" and in a sustainable condition.

In this paper, we discuss some of the direct consequences of aquifer depletion and then consider impacts in three disparate locations, California, Saudi Arabia, and India, which have been identified using GRACE data as being stressed to varying degrees. These locations have been chosen to illustrate some of the environmental, economic, and societal consequences of aquifer depletion. We conclude that groundwater depletion is a serious concern in many parts of the world, with far reaching implications for the sustainability of human civilization.

Direct Consequences of Aquifer Depletion

The lower groundwater levels that result from aquifer overuse and depletion can have myriad negative consequences, including increased extraction costs, decreased water quality, adverse impacts to aquatic species and riparian habitats, coastal saltwater intrusion, ground surface subsidence, and loss of "backup water" in case of short-term water shortages.

An immediate consequence of lower groundwater levels is an increase in the energy (i.e., cost) required to pump a given volume of groundwater. The greater the lift (i.e., the vertical distance between the groundwater level in a well under pumped conditions and the ground surface), the greater the energy needed to pump the same amount of water. This consequence is particularly hard-felt by those in poorer parts of the world who employ human energy to lift the water, which often limits the maximum depth from which water can be pumped (van Vark, 2013). Even for more developed groundwater users, greater input of mechanical energy means greater power consumption, cost, and associated emissions of heat-trapping greenhouse gases which contribute to climate change, possibly further harming water resources in a perverse feedback loop. Deeper groundwater levels may also require deepening of existing wells at substantial capital cost. Aquifers in which the groundwater levels have been drawn down through overuse tend to produce from deeper zones, where water quality is typically poorer as the groundwater tends to be older and to have had adequate time to leach inorganic ions from aquifer materials (Freeze and Cherry, 1979).

Under natural conditions groundwater contributes water to certain streams and rivers between periods of precipitation, because the groundwater level is higher than the streambed. Groundwater depletion, through lowering of the water levels, can result in a decrease or cessation of groundwater flow to streambeds, with negative consequences for aquatic species and riparian habitats. In coastal areas, groundwater depletion can result in a decrease in groundwater discharge to the ocean resulting in salt water intrusion and salinization of coastal aquifers, requiring costly water treatment or other mitigation measures such as barrier well injection systems (WRDSC, 2015).

In depleted aquifers, the reduced water pressure in pore spaces can cause the matrix of individual aquifer sediment grains, the “aquifer skeleton”, to bear more of the weight of the overlying sediments, resulting in vertical compaction of the matrix itself. This aquifer compaction manifests at the surface as land subsidence whereby the ground surface sinks, with costly damaging effects to surface infrastructure (Figure 2).

Groundwater is also often relied upon during dry periods as a supplement or substitute for surface water which may be unavailable. To the extent that groundwater resources are depleted or overdrawn themselves, they provide little in the way of a reserve to compensate for diminished surface water supplies during drought periods. This renders entire water systems, and the economies reliant on them, more vulnerable to droughts.

Case studies

On the basis of the Richey and others (2015) analysis of GRACE data, we focus on three important aquifers that have been identified as being “overstressed” or “variably stressed” to illustrate some of the wide-ranging impacts of aquifer depletion. These are the Central Valley Aquifer System of California, USA, the Arabian Aquifer System of the Kingdom of Saudi Arabia, and the Ganges-Brahmaputra Basin of India.

Central Valley Aquifer System, California, United States

California agriculture is a roughly $46 billion industry (2013), accounting for one third of the nation’s production of vegetables, two thirds of the production of fruits and nuts, and leading the nation with 12 percent of total cash receipts. Most of the state’s agricultural production occurs in the Central Valley, a 22,500 square mile alluvial basin stretching 450 miles from north to south bounded by the Sierra Nevada mountains on the east and the California Coast Range mountains on the west. The Central Valley owes its agricultural bounty to fertile soils developed on alluvial sediments shed from the Sierra Nevada, a climate that provides ample sunshine and moderate temperatures

Figure 2 – Land subsidence at groundwater extraction well due to groundwater withdrawal; well head, originally flush with the ground surface, is several feet above grade. Credit: Photograph from U.S. Geological Survey

ideal for growing, and a network of reservoirs, canals, and aqueducts built with major federal, state, and local investment that supplies farmers with surface water largely from captured Sierra Nevada snowmelt. Agriculture is further enabled by hundreds of thousands of deep irrigation wells tapping a single large groundwater aquifer which is recharged by the many rivers draining the Sierra Nevada. In normal years, groundwater constitutes roughly 38 percent of the state’s total water supply. This number rises to 46 percent, or more, in dry years. The ongoing historic drought in California has stressed surface water resources (Figure 3).

In addition to agriculture, the Central Valley is home to a population of 6.5 million people, including five metropolitan areas with over 500,000 people. In the two hydrologic regions

Figure 3 - Lexington Reservoir, California, after four years of drought - November 2015 Credit: Photograph by Carey E. Peabody

that comprise the southern portion of the Central Valley, the San Joaquin and Tulare Lake hydrologic regions, agriculture comprises 81% and 90% of groundwater use, with urban use comprising 13 and 10 percent respectively, with pumping to support environmental flows making up the remainder.

Despite California's substantial efforts to harness its surface water resources to support Central Valley agriculture, and advances in agricultural water use efficiency, farmers still rely heavily on groundwater. Encouraged by a profitable market for their agricultural products and a state constitution that grants landowners unlimited rights to pump groundwater for beneficial use on overlying lands, farmers have aggressively pumped from the Central Valley aquifer system in times of drought and, increasingly, in normal years as well. In the drier southern half of the Central Valley, total groundwater pumping from 2005 to 2010 averaged 9.4 million acre-feet per year (11.6 km^3/yr). The eight counties in these two areas pumped roughly 45 percent of the state's total groundwater during this same time period. This rate of extraction exceeds the rate of recharge, with groundwater overdraft of between 0.94 and 2.28 million acre-feet per year (between 1.16 and 2.81 km^3/yr), or approximately 10 to 24 percent of the total pumping rate. Between 1900 and 2008, researchers from the United States Geological Survey estimate a cumulative groundwater overdraft in the Central Valley of approximately 145 cubic kilometers (118 million acre-feet per year). The rate of groundwater depletion has been accelerating, with an average of 1.134 km^3/yr from 1900 to 2000 and a rate of 3.919 km^3 between 2001 and 2008 (Figure 4) (Konikow, 2013). The California Department of Water Resources classifies 11 of the 16 groundwater subbasins in the San Joaquin Groundwater Basin as in a state of "critical overdraft". According to the GRACE study (Richey et al., 2015), the Central Valley aquifer system is classified as "variable stress", indicating that extraction is occurring but there is also natural recharge that theoretically provides a chance to offset the extraction.

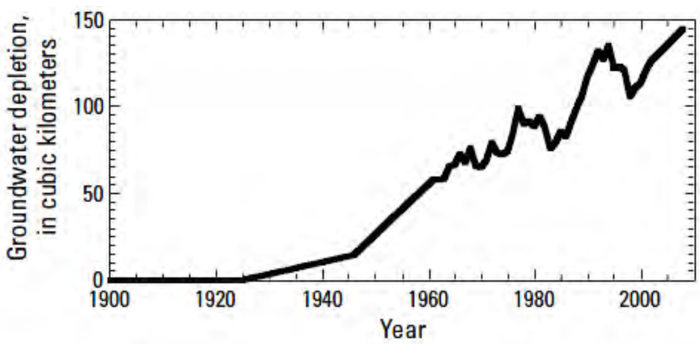

Figure 4. Cumulative groundwater depletion in the Central Valley of California, 1900 – 2008. Credit: Konikow (2013).

Groundwater depletion in the Central Valley has resulted in significant drops in the water levels in wells, in some places more than 100 m (Scanlon et al., 2012). In what some have termed a "race to the bottom", groundwater users in the Central Valley have been forced to drill ever deeper to keep up with the declines. Following three years of historic dry conditions, well drillers have been extremely busy, reporting backlogs of six months or more, and some farmers have even resorted to purchasing drilling rigs from other states (Richtel, 2015) (Figure 5). This situation has also led to a scarcity in rigs available to complete new municipal supply well projects, and decreased competition for those drilling projects, potentially increasing costs. In at least one town in the southern Central Valley, declining water levels resulting from long-term groundwater depletion and exacerbated by recent drought have caused private domestic wells to go dry.

Figure 5 – Drilling for Groundwater in California's Central Valley Credit: Photograph by Erler & Kalinowski, Inc.

Water level declines in the Central Valley in recent years have also depressurized aquifers resulting in renewed land subsidence in areas where this has previously occurred, as well as new areas of subsidence. The distribution of historic and potential future subsidence coincides with the areas experiencing the greatest groundwater depletion, namely the southern portion of the Central Valley, where 55 percent of wells with long (> 10 year) records exhibited water level lows between 2008 and 2014 that were below their previous historical low level (DWR, 2014). Subsidence can have significant and costly impacts to surface infrastructure including highways, aqueducts, and railroads.

The significant and accelerating depletion of groundwater aquifers in California and the historic recent drought were drivers for new legislation passed by the state legislature in 2014 aimed at addressing unsustainable groundwater depletion. The Sustainable Groundwater Management Act (SGMA) grants an array of new powers, and responsibilities, to local agencies with land use and/or water management authority, with a mandate to achieve sustainability goals within an approximately 25 year time frame. The law applies to all basins ranked as medium and high priority by the state and emphasizes local control and solutions, but also allows for state intervention if local entities are unwilling or unable to enact policies to achieve those goals. Hailed as a "game changer" to California's long-standing body of water law which until then placed few restrictions on groundwater pumping, the SGMA has spurred action among major groundwater users including those in the Central Valley aquifer system. While it remains to be seen if the law will have the intended effects (and without a doubt, any viable solution will inevitably entail some reduction in groundwater pumping), the law is forcing groundwater users to work together to seek ways to address groundwater overdraft through a consensus planning framework. The alternative to this consensus approach is a court-ordered basin adjudication, a notoriously contentious process wherein the private parties battle in court and a judge ultimately decides on an overall basin yield and then divides this yield among groundwater users, with steep penalties for those who pump in excess of their allotted amount. Whether the over-drafted basins end up being sustainably managed under cooperative agreements made under the SGMA or become subject to court-ordered pumping restrictions under adjudication, it appears that California has finally put in place laws that may eventually reduce groundwater depletion. However, given the degree of depletion that has already occurred, the long times-scales required for aquifer replenishment, and the continued demand on groundwater resources especially under the additional stress of climate change which may reduce available surface water supplies, it is unlikely that the Central Valley aquifers will return to their pre-development state anytime soon.

Kingdom of Saudi Arabia

In 1980, the population of the Kingdom of Saudi Arabia (KSA) was approximately 10 million people whereas today it is approximately 30 million (Countrymeters.info, 2016). Water is scarce and with the country's rapid population growth, the demand for water is increasing. Based on GRACE data, the Arabian Aquifer System is significantly "overstressed" (Richey and others, 2015), indicating that extraction is occurring and that under natural conditions the aquifer has a negative recharge rate (i.e., more water is lost to evaporation than is replenished naturally). Water shortages in the KSA are typical of the Middle East and North Africa areas that of course are also enduring extreme political stress.

With an average annual rainfall of 50 to 100 mm (2 to 4 inches), the KSA has no permanent rivers or lakes (Wagner, 2011). With such limited rainfall, Saudi Arabia relies on more than 200 dams to collect an estimated 0.45 cubic kilometer (km^3) of runoff annually (360,000 acre-feet/year), operates approximately 30 desalination plants to produce approximately 1 km^3 per year of potable water (890,000 ace-feet) per year, extracts groundwater from its aquifers, and is increasingly utilizing recycled water (Saudi Embassy, 2016).

The KSA was not always a desert. At the end of the last Ice Age, approximately 10,000 years ago, Saudi Arabia was covered with grasslands and river systems that over time gave way to the scrubland, deserts, and dry river beds (wadis) seen today. The deep groundwater aquifers that have been relied upon as a major source of water for the KSA contain water age-dated 15,000+ years old, related to melting of the European ice sheet (Wagner, 2011).

During the 1980s, Saudi Arabia embarked on a program of transforming the desert into farmland in order to become less reliant on food imports. The KSA supported the process by providing very inexpensive water to growers, providing infrastructure, and paying substantial subsidies for agricultural products (e.g., 5 times the world market price of wheat). Much of the water used for this program was nonrenewable "fossil" groundwater extracted from deep aquifers (Elhadj, 2004).

NASA photographs show the transformation of the desert to verdant fields (Figure 6). Green crop circles are evident beginning in the 1980s and peak in 2000. However, by 2012, irrigation was on the decline and the irrigated lands began to revert to desert. It has been estimated that during this period of 30 years, approximately 80% of the available groundwater was extracted and permanently consumed (Pearce, 2012).

The direct consequences of aquifer depletion in the KSA have included groundwater table decline, increased costs related to extracting groundwater from deeper in the subsurface, loss of historical desert springs and oases, decline in water quality as a result of poor water and wastewater management practices, and, along the coasts, seawater intrusion (Smith, 2003).

Despite these adverse impacts, the Kingdom of Saudi Arabia (KSA) continues to provide water at a very low cost to its citizens as part of its broad social welfare benefits. For example, for a family of 4 using 100 gallons per capita per day or 12,000 gallons of water per month, the cost for water is $1.23 per month. For comparison, the corresponding cost in the United States ranges from $23.26 per month in Fresno, California to $153.78 per month in Santa Fe, New Mexico (Circle of Blue, 2015).

At present, approximately half the water used in the KSA is produced by desalination but it is costly. In 2010, the total production and transmission cost for desalinated water was approximately $1.00 USD per cubic meter (Ouda, 2013) or almost 40 times the KSA residential rate. Over 95% of these costs were borne by the government. The energy required to desalinate water is provided largely from fossil fuels (CSIS, 2011).

Another response to limited water resources within the country and to preserve its existing water supply, the KSA in 2016 will cease subsidizing grain production within the country (Al Arabiya News, 2014). Instead, Saudis are also buying or leasing land in other countries to grow food for export back to the KSA, essentially utilizing the water resources of other countries. Saudi Arabian investors have reached agreements to implement this strategy with countries including Ethiopia, Sudan, Ukraine, and Pakistan (Shafy, 2010). In Ethiopia, for example, Saudi and other investors have made deals with the Ethiopian government giving them control over approximately half of the arable land in its Gambela region (Ferragina and Canitano, 2015). As part of the deal, the Ethiopian government has moved rural subsistence pastoralists and farmers from their homes into villages to make way for agribusiness (AAAS, 2015). Saudi investors have also consummated similar deals with Pakistan. Pakistan's investment

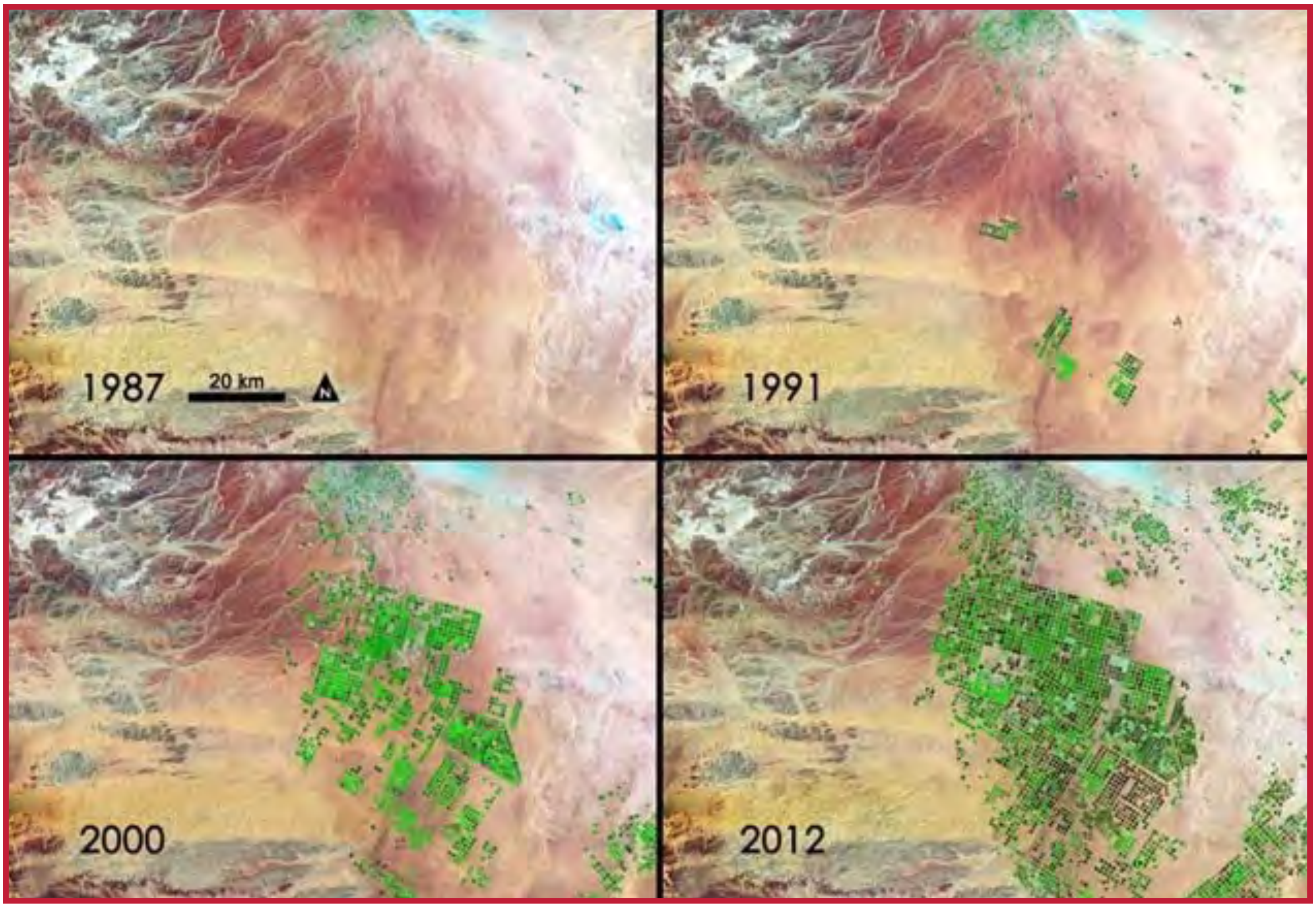

Figure 6 – Four Landsat images through time (1987, 1991, 2000, and 2012) that show the transformation of the Saudi Arabian desert to agricultural fields (each approximately 1 kilometer in diameter). By 2012, certain fields have reverted to desert. Healthy vegetation is bright green whereas dry vegetation in agricultural fields appears brown. Credit: NASA/GSFC

minister has assured Saudi investors that even if there were food shortages in Pakistan, 100% of any harvest could be exported back to Saudi Arabia, (Shafy, 2010).

Saudi agribusiness interests have also extended to the United States. In 2014, Saudi Arabia's largest dairy, al-Marai, bought approximately 40 square kilometers in the Arizona desert to grow alfalfa, a water-intensive crop, in order to export hay back to Saudi Arabia (NPR.org, 2015; Al Arabiya, 2014). Growing alfalfa for hay in the Arizona desert can make economic sense, given no immediate limit on pumping groundwater, because alfalfa will grow year round and approximately twice as much hay can be produced in the desert compared to farms in more temperate climates. The question remains, however, how long will the groundwater last?

What seems clear is that the impacts of water shortages in one part of the planet will not be contained and ultimately will be felt around the world.

Indus and Ganges-Brahmaputra Basins of Northern India

Northern India encompasses portions of the agriculturally important alluvial plains of the Indus, Ganges, and Brahmaputra Rivers, major rivers that convey runoff water and sediment from the Himalayas. It is one of the most populous regions on earth and is the 'bread basket" of India, essential for feeding India's current population of over 1.3 billion people. These rivers also traverse neighboring countries including Tibet, Pakistan, and Bangladesh. On the basis of satellite-based gravity data, Richey and others (2015) identify the Indus and Ganges-Brahmaputra Basins as exhibiting "overstressed" and "variable stressed" conditions, respectively.

Like California, the State of Punjab in the Indus Basin is a major source of food for India, providing nearly two thirds of grain production and a third of milk production in the country (http://punjab.gov.in/know-punjab). Its agricultural importance began in the 1970s when India launched its bid for food security with its "Green Revolution". With extensive subsidies from the government (i.e., including free electricity for farmers to run groundwater pumps), food production increased tremendously in the area with little regard, however, for energy costs or water efficiency. As a consequence, the Indus Basin aquifer is rapidly being depleted.

In the northwestern Indian states of Rajasthan, Punjab, and Haryana that are located in and near the Indus Basin, for example, Rodell and others (2009) estimate that for the period August 2002 to October 2008, groundwater depletion occurred at a rate of approximately 17.7 km^3/year. Data from India's Ministry of Water Resources confirms that water resources from this region have been "over exploited" (see Plate XXIII, p. 34, Central Ground Water Board, 2011). An analysis of rainfall records and water demand confirms the conclusion that northwestern India is under a high degree of water stress (Devineni, 2013). And local farmers report a drop in the water table on the order of 1 m/year (Betigeri, 2014). Nevertheless, little has been accomplished to date in terms of changing water policy and moderating groundwater extraction rates (Dhaliwal, 2015).

In comparison, water resources in the northeastern and eastern portions of India that encompass the Ganges-Brahmaputra Basin are less stressed. However, even here the availability of potable water is limited due to the poor quality of surface water coupled with the widespread occurrence of arsenic in groundwater extracted from shallow wells.

During the 1970s, it was recognized that an alternative water source was needed for the millions of people living on the floodplains of the Ganges and Brahmaputra Rivers because the surface water was polluted. In response, millions of shallow groundwater wells were installed by the World Health Organization with the objective of replacing damaged surface water with "clean" groundwater. What was not recognized until much later, however, was that the shallow groundwater contained elevated concentrations of arsenic.

Although the first cases of arsenic poisoning were recognized in the 1980s, understanding the full extent of the problem and rectifying it has been painfully slow. Arsenic has been detected at elevated concentrations in groundwater samples from wells located in eastern India (West Bengal), Bangladesh, and parts of Nepal (Singh, 2006). It has been estimated that many tens of millions of people from West Bengal, India and neighboring Bangladesh may have been exposed via well water to elevated concentrations of arsenic in drinking water above 50 parts per billion, 5 times the World Health Organization maximum contaminant level of 10 parts per billion (Singh, 2006; Smith and others, 2000). Termed "the largest poisoning of a population in history", exposure to arsenic can cause hyper-pigmentation, hyper-keratosis, skin cancers, and internal cancers including those affecting the lung and bladder.

Numerous studies have been conducted to determine the source of arsenic in groundwater. It has been determined that the arsenic occurs naturally in sediments associated with the floodplains of the Ganges and Brahmaputra Rivers and is adsorbed onto iron oxy-hydroxide minerals. Bacteria in the subsurface break down these minerals under reducing conditions, thereby releasing the arsenic to groundwater (Dowling and others, 2002).

Studies have shown that arsenic generally occurs in higher concentrations in groundwater collected from shallow aquifers compared to groundwater collected from deeper aquifers. As a consequence, some deeper wells have been constructed to avoid the highly contaminated shallow groundwater. There is a concern, however, that pumping the deeper aquifers could result in the downward transport of shallow, arsenic-contaminated water, thus spreading the arsenic to the remaining local source of clean groundwater.

A Global Phenomenon

Aquifer depletion is a global phenomenon that is most severe in areas of the planet with dense populations, limited precipitation, and unregulated irrigation. Direct consequences of aquifer depletion are discussed above. Some additional, perhaps surprising, aspects of aquifer depletion are discussed here.

During the last 50 years and in various desert areas around the world, for example, groundwater has been extracted from subsurface aquifers to make the deserts "bloom". We know now that in some cases this was a short-lived miracle as this groundwater was in fact "fossil water", some of which was emplaced in the subsurface when ice sheets melted at the end of the last glacial period, approximately 10,000 or more years ago. In Saudi Arabia, for example, groundwater from major deep aquifers has been radiocarbon dated at 16,000 years to greater than 34,500 years before present (Wagner, 2011). Groundwater in aquifers from nearby Middle Eastern countries including Kuwait, Bahrain, Qatar, United Arab Emirates, and Oman is similarly very old (Wagner, 2011). Studies of groundwater from the Nubian Sandstone Aquifer in Egypt suggest that the groundwater there may approach 1 million years old (Chapter 14.8 in http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1587_web.pdf). Fossil groundwater is a non-renewable resource. In such areas where there is little to no aquifer recharge, our generation of humans is effectively raiding the planet's water "bank account", leaving ourselves and future generations with enormous challenges with respect to sustaining human life and ecological systems.

Fortunately, there are aquifers with recharge rates that may be sufficient to balance more modest, future groundwater extraction rates. However, on the scale of large aquifer systems, it has been shown through modeling that basins may take hundreds of years to reach a new equilibrium after extraction rates change (Bredehoeft and others, 1982). Consequently, basins that are able to stop over-extraction through improved land use, agricultural, water efficiency practices, or other means, may still be faced with the legacy effects of excessive pumping for many years to come.

Making the goal of sustainable water use more elusive, climate change is expected to place added pressure on groundwater resources in many parts of the world. According to California's Department of Water Resources, for example, reduced surface water supplies may result from less snowpack, earlier and flashier runoff, and more frequent and prolonged droughts. In the last 100 years, average early spring snowpack has decreased by about 10 percent, or 1.5 million acre feet, sea level has risen seven inches along the West Coast, temperature has risen about 1 degree Fahrenheit (mostly at night and in winter and at higher elevations), and peak flows in most rivers have increased (DWR, 2008). DWR predicts that the Sierra snowpack which feeds California's most heavily relied upon river systems will decline 25 to 40 percent from the historic average by 2050. Water quality may be impacted by increased turbidity, stormwater pollutants, and seawater intrusion, and hydroelectric power generation may be impacted due to having to spill flashier runoff events, and less water may be available for the higher demand summer months.

Finally, global aquifer depletion is apparently impacting sea levels on the global scale. Groundwater that previously was contained within continental aquifers has been extracted and added to the surface/atmospheric portion of the hydrologic cycle much faster than it can re-enter the ground. As a consequence, Wada and others (2010) estimate that groundwater depletion has caused sea levels to rise 0.8 mm/yr, about 25% of total sea level rise rate of 3.1 mm/yr and about the same as contributions from melting glaciers and ice caps, excluding Greenland and Antarctica.

Conclusions

Groundwater aquifer depletion is a serious problem with wide-ranging implications for humankind's ability to maintain its current trajectory of population growth and increasing standards of living. While water quantity is the primary issue, water quality impacts are equally important. Drilling deeper typically results in more-costly extraction of water that is of worse quality due to higher concentrations of dissolved solids. Therefore, the current widespread practice of simply drilling deeper to obtain more water isn't a viable path forward.

Reducing our current reliance on groundwater is also likely to remain an enormous challenge in part due to our increasing population and the predicted adverse effects of climate change on surface water supplies. Achieving agreements on reductions in groundwater use within a given groundwater basin will require tough negotiations and compromises, perhaps analogous to the December 2015 climate negotiations in Paris. Will laws such as California's SGMA provide the necessary impetus to make these difficult decisions and avoid the "race to the bottom"?

Jim Hansen, an early contributor to this journal (i.e., Hansen, 2007), recently commented regarding the December 2015 climate negotiations in Paris that cutting greenhouse gas emissions will not occur to the extent required to prevent major climate impacts. "As long as fossil fuels appear to be the cheapest fuels out there, they will be continued to be burned" (Milman, 2015). In other words, until the true cost of emitting greenhouse gases is included in the price of fossil fuels, humans will not take the necessary steps to seek alternatives. Similarly, it appears that until the true value of water, including the economic, agronomic, social and environmental benefits it provides, is embedded in a more realistic price, humans will continue to use water inefficiently. At the same time, water is essential to sustain the lives of all 7.3 billion of us as well as those to come. It must not simply be allocated to the highest bidder.

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Endnotes

1 Not all precipitation reaches an aquifer because precipitation can run off directly to streams or get consumed by plants. Aquifer recharge only occurs when precipitation infiltrates below plant root zones and percolates to the water table.

2 The measured water level represents the water table in an unconfined aquifer and the potentiometric surface in a confined (artesian) aquifer. Whereas in an unconfined aquifer the lowering of water levels signifies the emptying of water from pore spaces in the aquifer, in a confined aquifer the decline in water level signifies a decrease in the pressure of the groundwater contained within the pore spaces.

3 See www.worldpopulationhistory.org for human population data compilation including online video that illustrates human population growth from the year 1 to the present and projection to the year 2050.

4 http://www.water.ca.gov/groundwater/sgm/cod.cfm

5 https://news.vice.com/video/flooding-fields-in-californias-drought

6 http://www.latimes.com/local/great-reads/la-me-c1-east-porterville-20140918-story.html

7 Reference for residential rate given in: http://www.dynamic-ews.com/Tariffs/Water%20Tariffs/KSA.pdf

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Urbanization and Demographic Change in Kentucky

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Introduction

Similar to many states in the U.S., the Commonwealth of Kentucky is undergoing significant demographic shifts. Three of these shifts – increasing urbanization, an aging population, and declining household size – are the subject of this article. These demographic trends have contributed to changes in the natural and built environment, and raise important questions about planning for our future. In what follows, changes in these characteristics over the past two decades are highlighted, and projections of future change are presented.

Urbanization

The U.S. Office of Management and Budget is responsible for creating delineations of metropolitan statistical areas (MSA) and micropolitan statistical areas (µSA) that are composed of one or more counties. The general concept of an MSA is meant to represent a substantial urban center of at least 50,000 people and any adjacent counties that have a high degree of integration with the urban area as measured by commuting flows. Similarly, µSAs represent urban centers with populations between 10,000 and 49,999, as well as any adjacent counties that have a high degree of integration with the urban area. The most recent definitions of MSAs and µSAs were released in 2013 and were used here to classify Kentucky's 120 counties into four categories along an urban spectrum. Counties within an MSA and containing the principal city of the MSA were classified as metro urban, counties within an MSA but not containing the principal city of the MSA were classified as suburban, counties within a µSA were classified as micro urban, and counties outside of these delineations were classified as rural. The one exception to these rules was for Kenton County, which is technically a suburban county of the Cincinnati MSA. However, this analysis classifies it as metro urban because the scope of this analysis is limited to Kentucky, and Kenton County contains the largest urban area on the Kentucky side of the Cincinnati MSA. Figure 1 depicts these classifications.

Recent population growth in Kentucky was not evenly distributed across the urban classifications within the state. According to data from the 2000 and 2010 Censuses, the state grew by 7% during this time. However, rural counties grew by less than 1% between 2000 and 2010, gaining fewer than 1,000 people during this ten year time period. At the same time, population growth in metro urban and suburban counties outpaced the state's growth, at 9% and 14%, respectively. In fact, the growth in these counties made up more than 80% of the state's population gains. Population growth in micro urban counties was close to the state average at 6%, but may increase in importance as population continues to shift away from rural areas.

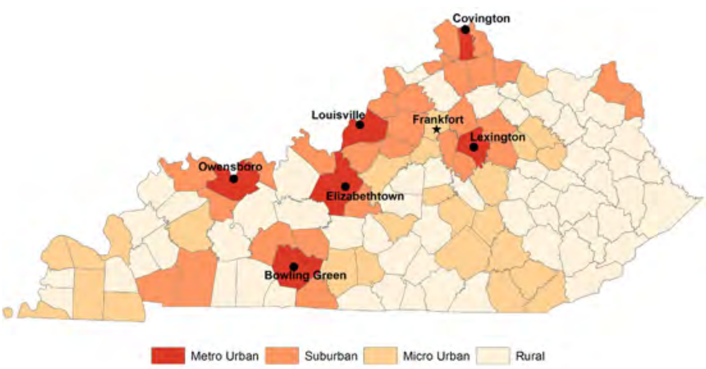

Figure 1: Kentucky Counties by Urban Classification

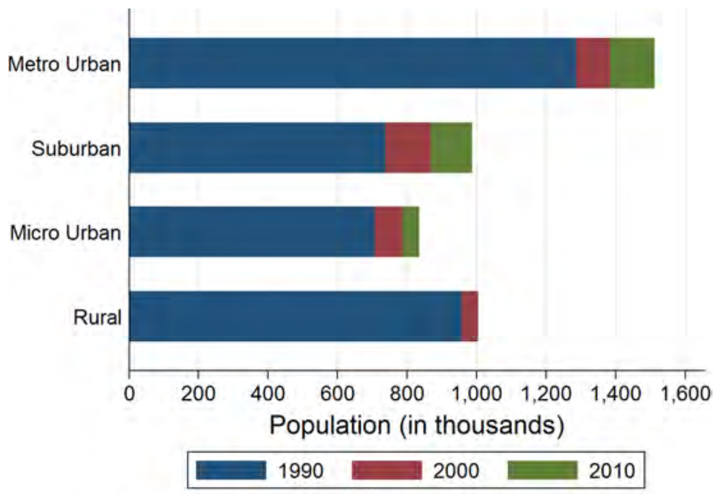

Figure 2. Population by Urban Classification and Decade

The primary components of population change are births, deaths, and net migration. The difference between birth and deaths, referred to as natural increase, has begun to level off in much of the United States. Net migration therefore serves as a pivotal determinant in how and where areas will grow in future years. Recent net migration data from the Applied Population Laboratory at the University of Wisconsin-Madison reaffirms that population growth patterns in Kentucky have become increasingly urban (Winkler et al. 2013). Between 2000 and 2010, Kentucky's suburban counties experienced the largest influx of migrants, followed by metro urban and micro urban counties. Rural counties experienced negative net migration during this time, resulting in the overall stagnation of population growth in these counties.

The Role of Urbanization in Human Ecology

Patterns of urbanization can sometimes be framed in a positive light when it results in greater population density. Overall, Kentucky's urbanization processes do not appear to be bringing about increased density. The pattern of urbanization within the Commonwealth has led to additional conversion of land into development, rather than increased density on the land that was already developed. Urbanization in Kentucky has also resulted in suburban development patterns, which are associated with longer commute times, increased traffic congestion, and air pollution. These development patterns are described in greater detail below.

Change in Developed Land

The National Land Cover Database (NLCD) uses remotely sensed imagery, augmented in some cases by cadastral data, to generate fine-scale classifications of all land within the contiguous U.S. (Vogelmann et al. 2001; Homer et al. 2007; Homer et al. 2015). NLCD products were released in 1992, 2001, 2006, and 2011, allowing researchers the opportunity to map land cover change over time. Although the NLCD does not unambiguously distinguish what might be characterized as "urban land", it does contain several classifications for land that displays "development". In this analysis, the four classes of developed land identified in the 2001 and 2011 NLCD products are grouped into a single developed class, and changes in development patterns between these two years are identified. Because the developed land classes in the 1992 NLCD are not directly comparable to those used in later years, the temporal change in land cover classifications identified in prior research is used to identify developed land change between 1992 and 2001 (Fry et al. 2009). More specifically, 1992 NLCD did not include the lowest density development class, which could potentially result in classification error when analyzing classification changes between 1992 and 2001.

It's important to point out that the NLCD evaluates land cover and not land use; as such, it is difficult to ascertain with certainty the exact characteristics of development (e.g., residential vs. commercial) observed for a given land area. Because it is based on remotely sensed data, the NLCD has imperfect validity; that is, the classification given by NLCD may not match what is actually on the ground. However, Wickham et al. (2010) report an overall accuracy for NLCD 2001 of 78.7% for the more detailed land cover classifications, and 85.3% for the more general classifications. There is also evidence that the NLCD performs less well – in terms of correctly classifying land – in rural areas, relative to urban areas (Smith et al. 2002). These limitations noted, the NLCD remains a useful tool for identifying broad patterns of development and identifying change in these patterns.

Developed Land Change between 1992 and 2001

In 1992, approximately 6.7% of Kentucky's total land area was developed land. Between 1992 and 2001, an additional 0.4% of the total land area changed from a non-developed (e.g., forest, farmland) class to a developed (e.g., urban) class. Although this seems like a small percentage, it represents nearly 145 square miles of newly developed land. Nearly three quarters of the land which transitioned to urban land between 1992 and 2001 was classified as forested land in 1992, with the other quarter classified as agricultural land in 1992. However, as noted above, remotely sensed imagery captures land cover and not land use, so the actual uses of this land in 1992 is somewhat ambiguous.

Unsurprisingly, the patterns of urbanization observed between 1992 and 2001 were not equally distributed across the state. Jefferson County – the state's most populous and most urban county – contained 6.6% of the state's total developed land in 1992, and nearly 10% of the land transitioning to developed between 1992 and 2001. Conversely, many counties with very small percentages of urban land saw nearly unmeasurable changes in the amount of developed land during this period. However, Laurel County (London), Pulaski County (Somerset), and Whitley County (Williamsburg/Corbin) all exhibited non-developed to developed land transitions that were much larger than might be expected given the prior urbanization patterns in these counties. This suggests that the development of new land in Kentucky is not only an issue for the metro urban counties, but also for the micro urban counties.

Developed Land Change between 2001 and 2011

An additional 110 square miles of land that was not developed in 2001 had become developed by 2011. Between 2001 and 2011, the transition from non-urban to urban land followed a similar pattern as in the 1990's, with the greatest amount of development occurring in metro urban counties (e.g., Jefferson and Fayette) and their suburbs (e.g., Boone, Oldham, and Jessamine Counties). By 2011, more than 50% of the total land in Jefferson County was classified as developed, a far greater percentage than in any other Kentucky county. Fayette (29.7%) and Kenton (28.1%) Counties exhibited the next largest developed land areas in the state. In 2011, the vast majority of Kentucky's counties (102 of 120) had urban land areas comprising less than 10% of their total land area.

Figure 3 shows the percent of land that was developed within each of the four urban classifications detailed above. The developed land percentage is distinctly higher in the metro urban

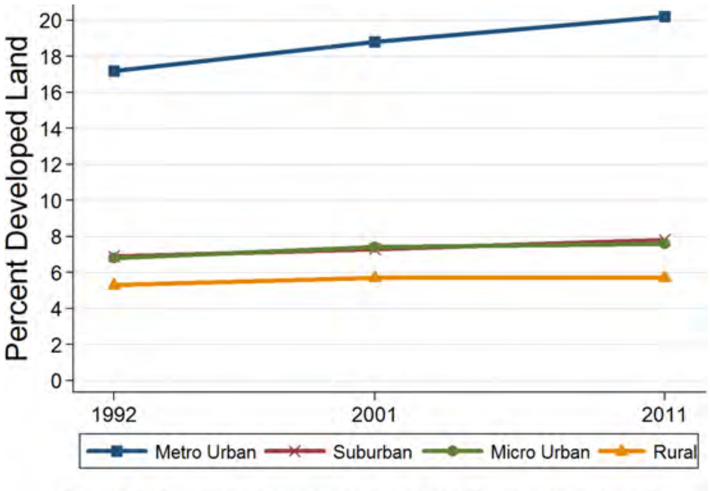

Figure 3. Developed Land by Urban Classification and Decade

counties, and is increasing at a greater rate. Yet developed land is increasing within each of the four urban classifications. The fact that suburban and micro urban counties have very similar levels of developed land is quite interesting, and runs contrary to expectations. However, the distribution of developed land within these two urban classifications appears to be somewhat different. Micro urban counties tend to have a denser cluster of developed land within the core of the county, surrounded by mostly undeveloped land in the remainder of the county. Suburban counties, on the other hand, often have developed land that is more evenly spread throughout the county.

Figure 4 displays the changes in developed land exhibited by a metro urban county (Jefferson) and a micro urban county (Pulaski) between 1992 and 2011. In these maps, pink areas are those that were initially developed and red areas are those that were newly developed during the period in question. These maps highlight that within both urban classifications, there was substantial development on the periphery of the existing developed area. Although it is not obviously apparent from these maps, this new development typically lies along new or existing transportation corridors.

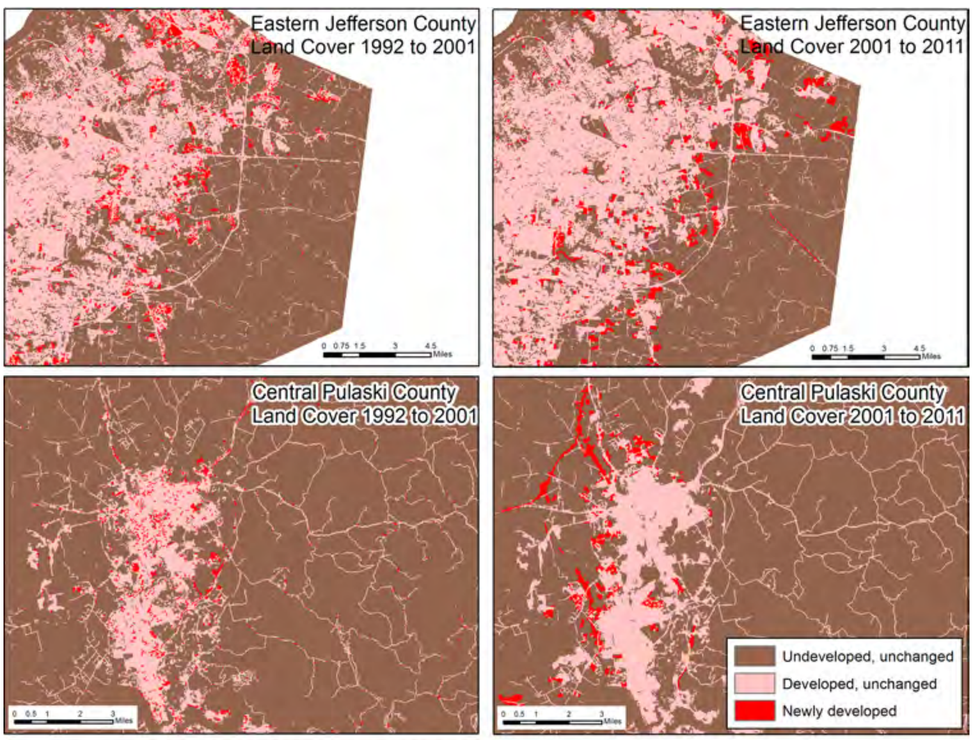

Figure 4. Examples of Developed Land Transitions, 1990-2010

Changes in Commute Patterns

Although suburban counties have made significant gains in total population, urban counties remain the largest employment centers in Kentucky. This has led to a larger spatial disconnect between workers' homes and jobs. The average commute time for Kentucky's workers in 1990 was 20.7 minutes, with 25% of workers' commutes taking more than 30 minutes and 5% of commutes taking more than an hour. By 2014, the average commute time for Kentucky workers had increased 2.1 minutes, reaching an average of 22.8 minutes, with 29% of commutes taking 30 minutes or more. The increase in average commute time was even larger in suburban counties, which gained an additional 3 minutes over this time period for an average commute of 25 minutes. More than a third (36%) of workers living in suburban counties commuted 30 minutes or more each way in 2014. The shortest average commute time was for workers living in metro urban counties, which in 2014 was 21 minutes, an increase of 1.5 minutes since 1990.

In 2014, there were an estimated 3,056,592 vehicles available to households in Kentucky, or approximately 0.714 vehicles per person. This was a slight increase from the 2000 value of 0.699 cars per household population, as well as the 1990 value of 0.652 cars per household population. The total number of vehicles available to households in the 2014 American Community Survey was 11.3% higher than the total number reported in the 2000 Census and 30.8% higher than the total number reported in the 1990 Census.

Population Aging

A visual representation of an area's age and gender distribution is often expressed as a population pyramid, as shown in Figure 5. Because they display the proportion of the population within each age group, they are useful visuals for gaining insight into an area's demographic composition. For example, the Baby Boomer generation, those born between 1946 and 1964, can easily be tracked in Kentucky's population pyramids over time as the large swell in the population moves up the pyramid.

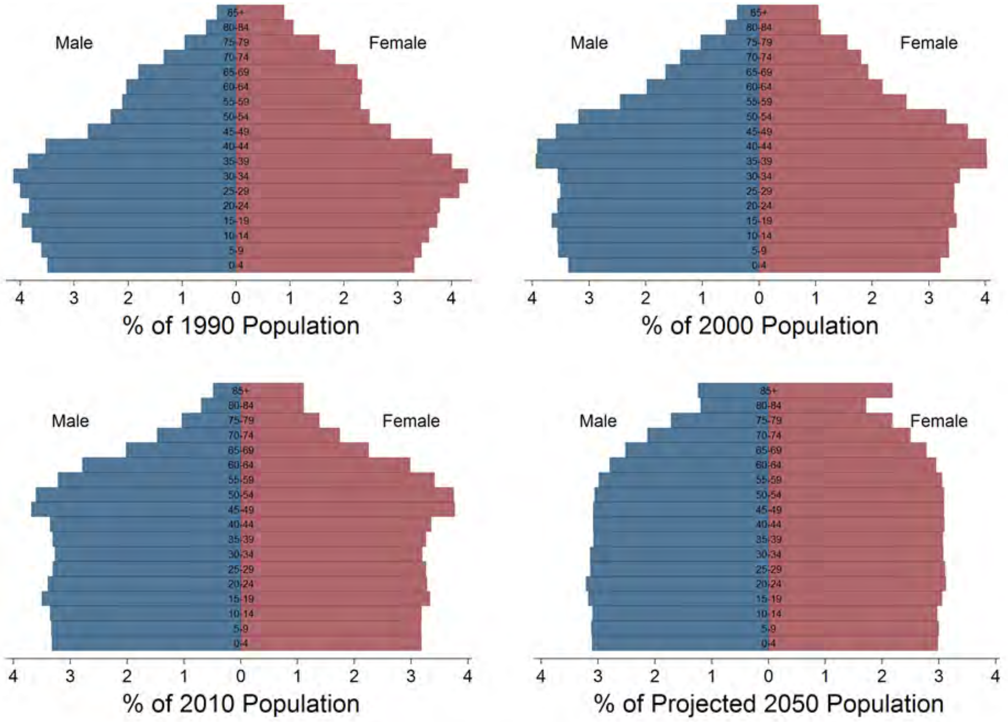

Figure 5: Kentucky Population Pyramids

Projections of Change in the Age Distribution

The population projections developed by the Kentucky State Data Center indicate the aging of the population will continue into the near future. As of the 2010 Census, 13% of Kentucky's population was aged 65 and over, a figure that is expected to rise to 20% by 2050. Within suburban counties, the population aged 65 and over comprised 11% of the total population in 2010, and this percentage is projected to nearly double (to 21% of the population) by 2050. Rural counties are forecast to have the highest relative concentration of older adults, comprising nearly a quarter (23%) of the rural population by 2050, up from 15% in 2010. Micro urban counties are also projected to realize sizeable gains in the proportion of older adults, growing from 15% in 2010 to 22% in 2050. Metro urban counties will also experience relative growth in older adults but of a smaller magnitude than other counties, growing from 14% in 2010 to 18% in 2050.

An important demographic trend becomes increasingly clear when examining Kentucky's population pyramids over time – the pyramid is becoming squarer in shape. While in 1990 and earlier decades, population in the younger age groups exceeded the population in the older age groups, by 2010 the population size of younger age groups is about equal with the population size of older age groups. As this pattern continues into the future, Kentucky will need to plan for a top-heavy age distribution and the associated resources, such as medical care, that will be necessary for an increasingly older population. Indeed, the relative number of the population age 65 years and over increased across all county groupings between 2000 and 2010. However, the smallest increase in the proportion of the older age group was in metro urban counties (0.1 percentage points) while the largest increase was in rural counties (1.4 percentage points).

The aging of the population is further reflected in the median age, which has increased over time. Between 2000 and 2010, the median age of Kentucky's population increased by 2.2 years, from 35.9 in 2000 to 38.1 in 2010. The increase in median age was even larger in suburban and micro urban counties, which both experienced an increase of 2.5 years in the median age. However the largest increase in median age was in rural counties which went from 37 years in 2000 to 40.1 years in 2010. Five rural western Kentucky counties – Lyon, Livingston, Hickman, Marshall, and Trigg – had median ages greater than 44 years in 2010, albeit with fairly small total populations. Meanwhile, in metro urban counties the aging of the population occurred at a slower pace, with the median age increasing only one year during the last decade, from 35.3 in 2000 to 36.3 in 2010.

The Role of Age in Human Ecology

Most studies on the effects of population aging have focused on how an older population will affect the economic, labor, and social insurance markets. Within the context of human ecology however, an older population is a more vulnerable population and will require targeted efforts to ensure a healthy quality of life. For example, the prevalence of disability in the population increases with age. Based on disability reporting in the 2014 American Community Survey, persons age 65 and older are more than 5 times as likely relative to persons younger than 65 to exhibit at least one ambulatory, sensory, or self-care disability. Prior research also suggests that older individuals are more vulnerable to emergencies or disasters (Hutton 2008).

One indicator on which Kentucky lags and which is likely to show a large effect in an aging population is that of air quality. Relative to the rest of the population, the elderly are at increased risk for the negative effects associated with outdoor air pollution. Research indicates significant short-term and chronic adverse health effects to the respiratory system from exposure to poor air quality on the older population (Bentayeb et al. 2012). Indeed, even after controlling for cigarette smoking and other risk factors, research indicates an association between poor air quality and higher mortality rates, specifically associated with lung

cancer and cardiopulmonary disease (Dockery et al. 1993). As of 2015, the U.S. Environmental Protection Agency had designated five Kentucky counties as nonattainment areas, wherein air pollution levels persistently exceeded the national ambient air quality standards. Planning for an aging population should aim to improve air quality standards across the Commonwealth.

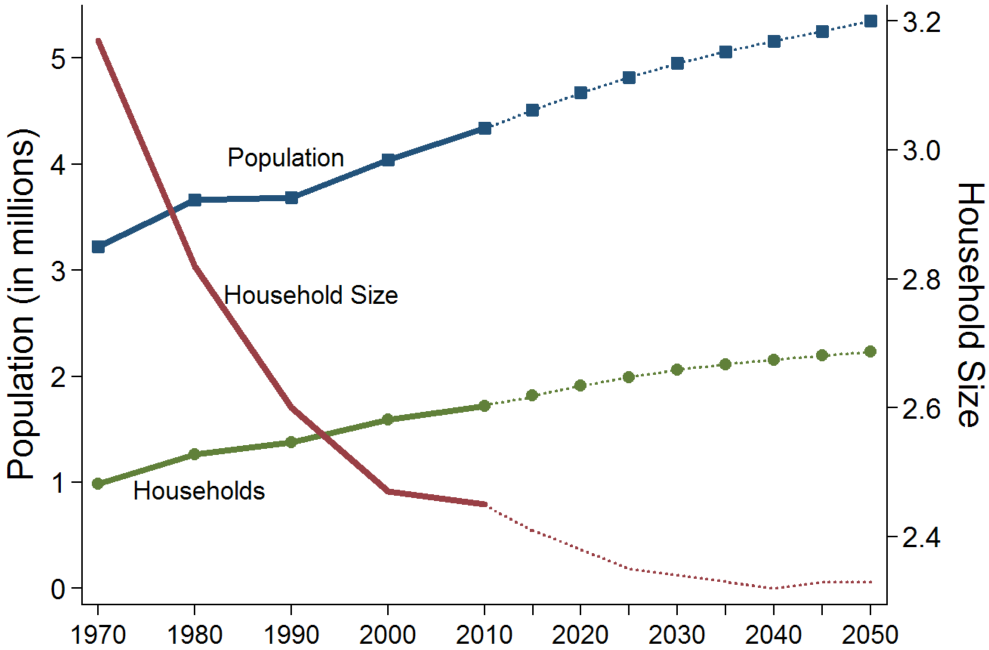

Figure 6. Total Population, Households, and Household Size, by Decade

Because older people are less likely to drive, the built environment plays a crucial role in shaping mobility options for older adults. A household with a householder who is age 65 or older is nearly twice as likely to have no vehicle available, relative to a household with a younger householder. These households and their occupants are more likely to use public transportation, if available, or rely on family or friends to provide transportation. Research also suggests that the elderly have less mobility restrictions when the built environment is designed in such a way that walking becomes a viable option. Specifically, street connectivity with shorter blocks, safety measures such as crosswalks, and proximity to retail and green space have been found to improve mobility in older adults and reduce the negative health outcomes associated with mobility restrictions (Rosso et al. 2011).

Changing Household Structure

Kentucky's households have gotten smaller in recent decades. The average household size in Kentucky fell from 2.6 persons per household in 1990 to 2.45 persons per household in 2010. Suburban counties had the largest average household size in 2010 at 2.59 persons per household; however this is still a decline from the 2.71 average in 1990. The largest decline in household size was in rural counties, which fell from 2.67 in 1990 to 2.45 in 2010. Metro urban counties consistently had the smallest household size, which in 2010 was 2.38. Projections developed by the Kentucky State Data Center indicate the trend in declining household size will continue into the future. By 2050, the average household size in Kentucky is expected to fall to 2.33 persons per household. Metro urban counties, micro urban counties, and rural counties are all expected to have similar household sizes by 2050, averaging 2.3 persons per household. Meanwhile, suburban counties are projected to retain the largest household size in 2050 at 2.4 persons per household.

The decline in household size is attributable, at least in part, to changing household compositions. Single person households have increased across Kentucky's counties, and in 2010 comprised 28% of all Kentucky households. The largest presence of single person households was in metro urban counties, which in 2010 made up nearly one-third of all urban households. The largest increase in the proportion of single-person households was in rural counties, which went from 21% of rural households in 1990 to 26% in 2010. The rise of single-person households can be partially attributed to an aging population. In 2014, approximately 24% of all Kentucky householders were age 65 or greater, while 10% of all householders were age 75 or older. However, among householders in single-person households, more than 37% were age 65+ and nearly a fifth were age 75+. The rise of single-person households can also be linked to young people waiting longer to get married. The percentage of Kentucky's marrying age population who has never been married increased five percentage points between 1990 and 2010, reaching 28% in 2010. In metro urban counties, a third of the marrying age population has never been married, an increase of 7% since 1990.

The Role of Household Size in Human Ecology

The increase in single person households and corresponding decline in household size implies that there may be a loss of efficiency in terms of resources used per person. The household-level economies of scale enjoyed by larger households, such as shared food, shared vehicle usage, and energy costs, diminish as the mean household size decreases. Prior research indicates that there exist important environmental implications for changes in household structure (Bradbury et al. 2014). These authors stress the importance of considering household dynamics – and not just population growth – in identifying the impact of population on the environment, and highlight possible responses to rapidly increasing household and housing growth.

Conclusion

This brief exploration of past and future demographic trends indicates that Kentucky's environment is being influenced by several simultaneous factors. There is little historical precedent for the rapid population aging and changing household composition observed in this study. More research on the effects of these demographic forces on the natural and built environment is unquestionably warranted.

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Coal Mining in Kentucky: Challenges and Opportunities in Protecting Human Health and the Environment

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Coal mining in Kentucky has divided generations of people that aggressively support or oppose the practice. Even for those that have a limited or no opinion on the issue, coal mining affects most, if not all of those who live in the Commonwealth. From relying on coal for electricity generation, to being directly or indirectly employed in the mining industry, to living near a mine site or leasing property to a mining company, to being exposed to pollutants generated from a mining operation or coal fired power plants, coal mining has far reaching effects on human ecology.

Despite mounting evidence that coal mining and the use of coal has impacts on human health and the environment that are not being adequately controlled, coal mining proponents frequently decry any attempts at more strict regulations on the industry. In fact, a culture has developed, originating in West Virginia, that paints supporters of the coal mining industry as “Friends of Coal” and necessarily labels anyone else an opponent of economic growth and good paying jobs. Similarly, the federal government’s attempts to provide greater protections to human health and the environment through tighter regulations has been dubbed the “War on Coal.”

However, while the coal industry and its supporters seem to be unwavering in their efforts to block any increased regulation on the industry, opponents of the industry are equally steadfast. Opponents of the industry persistently demand a ban on steep slope surface mining in Appalachia, commonly known as “mountaintop removal mining.” In addition, anti-mining citizens groups continue to staunchly advocate for bans on the placement of any fill material or mine waste in streams, which would effectively eliminate the vast majority of surface and underground mining in a region that produces approximately 15 percent of the coal mined nationwide.

This battle of extremes is fraught with issues that have long prevented the parties from working together to reach a middle ground. In some cases bad information is used to support positions or information is skewed to support a party’s position. In other cases, regulators that are charged with enforcing the laws that currently exist to protect public safety, health, and the environment have blatantly allowed coal companies to mine in contravention of these rules. Still in other cases, coal companies have intentionally falsified data in order to avoid complying with the law. In addition to the tension already surrounding the practice, these issues have created an extreme distrust between the parties and a further distrust by citizens of the government that is charged with protecting them.

Thus, this article seeks to provide a balanced analysis of coal mining in Kentucky, with a focus on how pollutants generated from mining operations can impact human health and environment, and what challenges and opportunities exist in providing better protections while ensuring continued access to reliable and affordable electricity in the state. The article will begin with an overview of the basic engineering, economic, and geologic principles involved in Kentucky coal mining. The article then discusses the effects coal mining can have on the environment and public health and what laws, regulations, and other constraints are currently in place to prevent or limit those impacts. Finally, the article discusses whether these laws and regulations are effective and what challenges and opportunities exist to better protect public health and the environment in Kentucky coal mining communities and beyond.

I. Coal Production and Mining Practices in Kentucky

In order to fully understand how coal mining impacts human ecology and the laws and regulations that govern coal mining operations, it is essential to have an understanding of the various techniques used to mine coal in Kentucky and the overall mining process. This section also discusses coal production trends in the state in order to provide an economic perspective on the industry.

A. Coal Production in Kentucky

Kentucky produces more coal than all but two other states, with production reaching 80.5 million tons in 2013. In addition,

coal supplies upwards of 90% of Kentucky's energy needs and Kentucky has some of the cheapest electricity rates in the nation. However, coal production in Kentucky has been steadily declining in recent years. From 2012 to 2013 alone, coal production in Eastern Kentucky decreased by19 percent and reached the lowest level since 1962. Since peak production of 131 million tons in 1990, coal production in Eastern Kentucky has dropped by 70 percent. In addition, coal production in Kentucky seems to be shifting toward Western Kentucky, where thicker coal seams exist and the market price of the coal itself is cheaper. In 2013, total annual production from Western Kentucky was greater than in Eastern Kentucky for the first time since 1911.

This shift in coal production from Eastern to Western Kentucky, and the decline in production in general, is happening for several reasons. First, the resource itself has become more expensive to extract in Appalachia as most of the high quality thicker coal seams have been mined. In addition, natural gas prices have plummeted in recent years, resulting in the closure of some coal fired power plants and competition from the natural gas industry. Uncertainty surrounding greenhouse gas regulations has also impacted the construction of new coal fired power plants. The type of coal produced in Appalachia is more high quality and thus more expensive, while the coal produced in Western Kentucky is lower quality and contains high sulfur content. As more coal-fired power plants install scrubbers, they will be able to burn Western Kentucky coal or coal from other regions with lower delivery costs.

B. Coal Geology in Kentucky

Coal forms when dead plant material is covered by sediment. Heat and pressure over millions of years change the chemical composition of the plant material to form coal. Each coal deposit has a different chemical composition, but coal generally contains carbon, hydrogen, nitrogen, oxygen, ash, sulfur, moisture content, and minerals such as silicon, aluminum, iron, calcium, and others.

Coal is ranked based upon various factors including carbon, heat and moisture content and the presence of volatile matter. The higher the carbon and heat content and the lower the levels of moisture and volatile matter, the higher the rank. Coal is classified into four ranks from lowest to highest: lignite, sub-bituminous, bituminous, or anthracite. Coal also has different uses depending on the type of coal. Steam coal is typically used by coal fired power plants and the vast majority of coal mined in Kentucky is used as steam coal. Metallurgical coal is typically used by the steel industry to produce coke. Metallurgical coal contains low amounts of ash and sulfur and is typically found in Eastern Kentucky and sells for a higher price than steam coal.

The coal that is mined in Kentucky comes from two separate geologic areas, which are the Illinois Basin in Western Kentucky and the Appalachian Basin in Eastern Kentucky. Coal from the Illinois Basin in Western Kentucky is typically bituminous, but has a lower heat content and a higher sulfur content than coal from Eastern Kentucky. Eastern Kentucky coal has one of the highest average heat contents in the country and low sulfur content. Eastern Kentucky coal also sells for about 60% more per ton than Western Kentucky coal, which is due to the quality of the coal, as well as mine productivity, transportation costs, and other factors.

Historically, demand for Eastern Kentucky coal was high due in part to its low sulfur content that allows the coal to be burned while producing less sulfur dioxide emissions. However, more recently power plants have begun installing pollution control technologies that allow them to purchase cheaper coal with higher sulfur content, like that mined in Western Kentucky.

C. Mining Methods in Kentucky

Coal is mined by either surface or underground mining methods. The method used to mine coal at any given site is determined by the terrain, the characteristics of the coal deposit, including seam thickness, the hydrology of the area, and the amount of soil and rock, called overburden, that overlays the coal seam. In 2013, approximately 68 percent of coal mined in Kentucky came from underground mining, while 32 percent was produced using surface mining methods.

Underground mining methods differ based on the mining method and how the mine is accessed. Mines can be accessed by drifts, slopes, or shafts. Two main methods of extracting the coal are room and pillar mining and longwall mining. In room and pillar mining, coal is mined in "rooms" while pillars of coal are left behind to support the roof. This method results in lower productivity, since the coal making up the pillars is left behind. Coal is extracted using a continuous miner or by conventional methods where the coal is cut, drilled, blasted, and loaded on to cars. Longwall mining uses a machine to cut out all of the coal in long tunnels. While mining occurs, temporary roof supports are used. Once the coal is mined, the unsupported roof behind the machine is allowed to collapse.

Surface mining methods generally involve removing the overburden above the coal seam and then extracting the coal. First, the surface vegetation and trees are removed and then the operator removes the topsoil using bulldozers or scrapers. The topsoil is stockpiled for later use or spread over an area that has already been mined. The remaining overburden made up of sub-soil and rocks overlying the coal seam is then drilled or blasted and removed. Once the coal is exposed, it is removed by fracturing or blasting and then loaded onto trucks to be hauled away. The overburden that was removed during mining is typically placed back onto the mined out area and graded and compacted. When overburden is removed it typically swells to about 25% larger than its original size since it is no longer compacted in the earth. In steep terrain like Eastern Kentucky, the amount of overburden remaining post-mining is almost always greater than the amount that can safely be placed back on the mountain while maintaining stability. Thus, any excess spoil remaining after mining is deposited into adjacent valleys in the form of a compacted and constructed fill. After grading and compacting, the topsoil is then spread on top of the mined area and the operator seeds and revegetates the area.

Types of surface mining include area mining, contour mining, highwall and auger mining. Area mining typically occurs on flat land over a large area. The overburden is removed by excavating machines to access the coal seam below. Contour mining occurs almost exclusively in Eastern Kentucky and is the process of removing the part of the overburden along the coal outcrop on the side of a hill to form a bench. Auger mining can then be used to drill into the coal seam to access additional coal without removing the overburden.

II. Environmental Effects of Coal Mining

Coal mining can contribute to a wide range of environmental impacts and impacts to human health. Rather than attempt to discuss all of these, this section will focus on three key environmental concerns related to coal mining that also impact human ecology: water pollution, hazardous air pollutants, and greenhouse gas emissions. This section will provide a brief overview of how coal mining can contribute to these issues and what effect these sources of pollution can have on human ecology. The next section provides an overview of the laws and regulations that are in place to limit or prevent these problems, followed by an analysis of how improvements in these areas could be made in the future to better protect human ecology and the environment.

Water Quality

Surface and underground mining can both cause adverse impacts to water quality, even in spite of existing regulations. Water pollution from surface mining can occur in a variety of ways. When a mine site is reclaimed, changes in the topography of the land occur, which can alter previous drainage patterns. The removal of vegetation during the mining process results in exposed surfaces that can increase surface water runoff. Improper reclamation can result in erosion and flooding, especially when a large part of a previously forested mine site in a steep slope area is left unreclaimed. Constituents such as selenium, that are present in overburden that is broken apart by mining and that were previously isolated from surface water and groundwater can cause water pollution if they are not handled properly and isolated during mining and reclamation. Surface mining can also result in increased sedimentation in streams and other water pollution and can cause changes in groundwater and surface water quantities and flow patterns.

Even under existing regulations, mining can affect downstream water chemistry. Numerous studies have found that waters downstream of mining areas tend to have higher levels of aluminum, manganese, sulfate, and iron, and high levels of conductivity and total suspended solids and that the damage caused by these elements can last for decades. Excess spoil fills constructed during steep slope surface or contour mining completely destroy stream segments, resulting in increased concentrations of ions in receiving waters both during and after mining reclamation.

Underground mining can also affect water quality. The mining process can expose rocks containing pyrite, which when exposed reacts with air and water to form sulfuric acid and dissolved iron. This is commonly called acid mine drainage and impacts streams outside the mine site by making them more acidic. Longwall mining can cause subsidence, which can temporarily, or in some cases, permanently dewater streams.

Impacts to human ecology and human health resulting from these potential impacts are varied and likely site specific. While numerous studies in recent years have found correlations between certain health impacts (ranging from birth defects to cancer and others) and living near areas where coal mining occurs, little evidence exists in the published literature that health impacts to specific individuals were actually caused by coal mining operations. However, what we do know is that coal mining operations can cause the elevation of certain chemical constituents in water bodies and drinking water or cause other water related impacts that can affect human health and safety.

For example, selenium can be a potential human health hazard for people living or recreating near coal mines because it is bioaccumulative, meaning that even low concentrations can increase in fish and wildlife. Thus, recreational users or subsistence anglers may be exposed to high levels of selenium, which can result in health impacts to the endocrine system. Acid mine drainage can affect drinking and industrial water and causes water discolorations and reduced ph, which can prohibit recreational opportunities. Other metals, such as arsenic, have been found in drinking water near coal mining operations and can play a role in the cause of some cancers. In addition to contaminated drinking water and impacts to recreational opportunities, coal mining operations that are not properly reclaimed can cause serious flooding, which can destroy homes, communities, property, and even cause death. For example, a 2010 flood in the Harless Creek watershed in Pike County, Kentucky, allegedly occurring in part due to an unreclaimed mining operation, caused approximately $5 million in damage to about 100 residents living in the valley below. Other similar flooding events have occurred in Kentucky in recent years.

Air Quality and Greenhouse Gas Emissions

Coal mining can cause air quality impacts that affect human ecology both on and off the mine site. Coal mining itself can generate air pollution, mostly particulate matter, in a variety of ways. These include blasting the overburden to get to the coal seams below, wind eroding exposed areas, and the handling of coal at the mine or at processing plants. In addition, after coal is mined, it is typically loaded onto large trucks and transported off-site via public roads that travel through communities. These trucks can generate dust by tracking dirt and other material from mine site to the paved roads. Dust can also be generated directly from the truck itself.

A recent study analyzing the impact of surface coal mining operations on PM10 concentrations near the mine in Roda, Virginia found that residents of Roda may be frequently exposed to PM10 concentrations above the Environmental Protection Agency's recommended standards. The data uncovered by the study indicates that coal mining activities may be heavy contributors to local air pollution, especially since due to the mountainous terrain, homes in Appalachia are typically located close to roads and in valleys where air pollutants tend to concentrate. Exposure to these types of hazardous air pollutants has been correlated with cardiovascular and respiratory mortality and may exacerbate pre-existing respiratory conditions, such as asthma.

In addition, coal miners can also be exposed to coal dust particles while on the job, which can cause or contribute to a host of chronic health issues. The most commonly known health impact, Coal Worker's Pneumoconiosis, commonly called "black lung," is an occupational disease that occurs after exposure to excessive amounts of respirable coal dust over an extended period of time. Black lung can cause severe respiratory problems and even death.

Greenhouse gas emissions, while commonly associated with emission from coal fired power plants, can also occur at coal mining operations. If a mine is located in a forested area, the trees are completely removed, which releases any trapped carbon dioxide into the atmosphere. Current regulations contain specific requirements related to revegetation of the mine site after reclamation, but reforestation of previously forested areas is not currently a requirement. Coal seams and surrounding rock can house methane, another greenhouse gas, and this can be released during mining. Underground coal mining typically results in greater methane releases than surface mining since deeper seams generally contain higher methane contents due to the increase in pressure. Some mines contain degasification systems that trap and use the methane gas generated from coal mining.

In summary, the affects of coal mining on human health, ecology, and the environment, are highly dependent on site specific factors. These include the type of mining that is occurring, the location of the mine, the topography, hydrology, and geology of the area, where people live compared to the mine, how the mine is operated, pollutants present pre-mining, and how the mine is reclaimed. To date, few published studies have found more than a correlation between health impacts and coal mining. However, there is no question that coal mining can produce pollutants that can harm human health and the environment, but whether and to what extent this is occurring is site specific in nature. In addition, as discussed in the next section, various laws and regulations address these potential impacts to varying degrees and are discussed in more detail below.

III. SMCRA AND FEDERAL MINING REGULATION

A. Federal and State Roles in Coal Mining Regulation

As described above, coal mining, like most industrial activities, can cause extensive environmental damage if left unregulated and these environmental consequences are partially what led to the passage of the Surface Mining Reclamation and Control Act of 1977. Section 102 of the Act states, "It is the purpose of the Act to, (a) establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations; . . ."

The Surface Mining Reclamation and Control Act ("SMCRA") was enacted in 1977 and establishes minimum federal standards for the regulation of coal mining. In addition to SMCRA, the federal government, through the Office of Surface Mining ("OSM") also promulgates regulations implementing the law. SMCRA is an example of cooperative federalism, where each state may propose its own program to regulate coal mining that meets or exceeds the standards set out in the federal program. Once the Secretary of the Interior approves the state program, the state gains "primacy," or primary control over the regulation of surface mining in its state and promulgates and implements regulations interpreting its program. The Office of Surface Mining regulates coal mining according to the federal program in states that do not submit programs or submit inadequate programs. Currently all states with coal mining operations have their own programs except for Tennessee and Washington.

While states have primary control over their programs, the Office of Surface Mining ("OSM") is responsible for overseeing the administration of each state program and can also take over any state program that is not being administered in accordance with the federal regulations. OSM also retains several other powers in regulating coal mining in states with their own programs. These include enforcement authority over individual mine sites, the ability to stop a permit from being issued, the ability to conduct a federal inspection of a specific mine site upon citizen request, and the ability to take a direct enforcement action against a specific mine site.

B. Basic Scope and Provisions of SMCRA Regulation

SMCRA applies to all surface coal mining operations in the United States and the surface effects of all underground mining operations. It also regulates coal processing and coal preparation facilities, coal waste piles, and coal loading facilities located at or near a mine site.

i. Permitting

SMCRA requires that all operators acquire a valid permit from the state regulatory authority prior to engaging in mining operations. To get a permit, the operator must submit a permit application that outlines in detail information about the proposed operation, including information about the operator such as financial status, history of complying with the law, and legal status, information about the area to be affected, including current data on ecology, geology, and hydrology, and the proposed mining

and reclamation operations. The operator must show through the application that all requirements of SMCRA will be met and that the area can successfully be reclaimed according to SMCRA's requirements.

The operator is also required to obtain appropriate bonding and insurance. Bonding is required to ensure that if the operator abandons the operation or fails to comply with permit requirements, sufficient funds will be available to reclaim the land according to the Act. Insurance is also required that is sufficient to cover damage to property or personal injury resulting from the mining operation.

The state can impose permit conditions to limit damage or can refuse to issue a permit if mining cannot be accomplished without violating provisions of the Act. Permits are issued for 3-5 year periods and must be renewed. If the operator wants to change the way it will conduct the operation, such as adding additional acreage or changing the way in which the coal will be mined, the operator must submit an application to revise the permit and get agency approval.

ii. Performance Standards

Once the operator obtains a permit, SMCRA sets out performance standards that an operator must adhere to during and after mining. These standards include the requirement to restore the land to its approximate original contour, minimize disturbances to the hydrologic balance, reclamation requirements, and standards relating to blasting, protection of wildlife, road construction, and for disposal of excess spoil material. Special standards relating to steep slope areas are also relevant to mines in Eastern Kentucky that are located in steep, hilly terrain. The operator must comply with these and all other provisions of the Act and all permit conditions. In addition, the operator cannot conduct operations in a way that would result in an imminent threat to the environment or public health and safety.

iii. Inspections

In order to ensure that operators are complying with the law, SMCRA requires mandatory inspections by the state regulatory authorities. SMCRA requires at least one complete inspection per quarter and one partial inspection per month by the state regulatory authority. These inspections are conducted without providing advance notice to the operator. If an inspector uncovers a violation of SMCRA, the inspector is required to take enforcement action. The inspector should issue a Notice of Violation ("NOV") if the violation does not cause imminent harm or endanger the public health or safety. The NOV gives the operator a set time (less than 90 days) to correct the violation and outlines steps needed to fix the problem. If the problem is not fixed by the time limit, the inspector must issue a Cessation Order ("CO"). COs may also be issued when the inspector uncovers a condition that poses an imminent threat to public health or safety or has the potential to cause significant environmental harm.

Operators can be subject to civil penalties and criminal prosecution for repeated, willful, and/or negligent violations of SMCRA. A penalty must be assessed when a CO is issued and a penalty for the issuance of a CO for failing to abate an NOV is required for each day the violation continues.

In addition, a permit can be suspended or revoked where the agency finds that the operator is willfully violating SMCRA or conditions of the permit. Once the agency issues a suspension order, the operator must "show cause" as to why the permit should not be suspended or revoked. The permittee can request a formal hearing and citizens can participate in these proceedings as intervenors.

iv. Citizen Involvement

SMCRA also provides an unprecedented level of citizen involvement in the regulation of coal mining operations. While the state regulatory authority has certain obligations under the Act, SMCRA also provides for citizen involvement at most stages of the process, from permit issuance, to inspection, to bond release. Any citizen who has an interest that is or may be adversely affected by the proposed mining operation can file written objections to a permit application with the regulatory authority and can request an informal conference to discuss the objections. After assessing the objections, the regulator must make a decision to grant or deny the permit. If the citizen is unhappy with the decision, a formal administrative hearing can be requested, which allows both sides the opportunity to present evidence, cross-examine witnesses, and have the case heard by an impartial hearing officer. Decisions of the hearing officer in Kentucky are appealed to state court.

Citizens also have the right to request that the regulatory authority inspect the mine site where a violation of the Act is occurring. Citizens have the right to accompany the inspector on the inspection and the inspector must notify the citizen in writing as to what enforcement action was taken, or explain why no action was taken. Citizens and operators can also review NOVs and COs and request formal administrative review of the action.

Finally, SMCRA allows any person having an interest that is or may be adversely affected to bring a civil suit to compel compliance with SMCRA. Cases can be brought against the United States or other governmental agency that is in violation of the Act, implementing regulations, order, or permit or any permittee in violation of the Act, implementing regulations, order, or permit. A citizen may also bring an action to compel compliance with the Act against the Secretary or the appropriate state regulatory authority where there is alleged a failure to perform any non-discretionary duty under the Act. Finally, citizens can bring actions for damage to property or personal injury resulting from a violation of the Act, regulation, order, or permit. SMCRA also authorizes the recovery of costs and attorneys fees where the citizen prevails.

v. Bonding and Bond Release

Once mining on all or part of a permit area is complete, the operator can apply to have its bond liability released. There are three phases of bond release, known as Phase I, Phase II, and Phase III. Phase I bond release occurs when the area is backfilled and regarded and the permit terms relating to drainage control have been complied with. If Phase I bond release is approved, 60% of the bond liability is released. Phase II release occurs when vegetation has been successfully re-established and ph and sediment are in compliance. Finally, Phase III bond release occurs when revegetation has been successful for 5-10 years. At this point, the entire remaining bond amount is released. As described above, citizens also have the right to contest bond release requests and ask for an inspection of the site during bond release proceedings.

C. Kentucky's Regulatory Program

Kentucky has primacy of its program and regulates surface mining in the state through the Department of Natural Resources, which is housed in the Energy and Environment Cabinet. Kentucky's program regulating coal surface mining is located at KRS Chapter 350, with implementing regulations located at Title 405 of the Kentucky Administrative Regulations. Under Kentucky law, the state program can be no more stringent than the federal program. Under federal law, Kentucky's program can be no less stringent than the federal program. Thus, Kentucky's program, while not identical to the federal program, is substantively the same. However, OSM has been attempting to overhaul its regulations on the federal level for several years, meaning once those regulations are promulgated, Kentucky would have to revise its regulations to be consistent with federal rules and have that regulatory program approved at the federal level.

D. The Clean Water Act

The Clean Water Act ("CWA") has a purpose of "restor[ing] and maintain[ing] the chemical, physical, and biological integrity of the Nation's waters . . . ." Thus, the CWA prohibits point source discharges of pollutants into waters of the United States unless consistent with the mandates of the CWA. Two CWA permitting programs allow coal mining operations and other industries to discharge pollutants into these waters. Section 402 of the CWA governs the discharge of pollutants other than dredged or fill material, such as discharges from sediment control ponds, while Section 404 authorizes the discharge of dredged or fill material, such as the construction of valley fills or mining through streams. Section 402 permits are typically issued by state-authorized permit programs with oversight by the U.S. EPA. Section 404 permits are issued by the U.S. Army Corps of Engineers.

Under CWA Section 303, states must adopt water quality standards for the water bodies in their states that are designed to maintain the chemical, physical, and biological integrity of the waterbody for the uses for which it is designated, such as drinking water, recreation, or other uses. State agencies issue Section 402 permits to the mining company that limit or define a certain level of discharge of pollutants so that the designated use of the water body into which the discharge will occur is maintained.

In order to receive a Section 404 permit to either construct a valley fill or mine through streams, the mining operator must submit a permit application to the U.S. Army Corps of Engineers, which among other things, demonstrates that the applicant has analyzed available alternatives to the proposed mining plan and has chosen the least environmentally damaging alternative and that the alternative complies with various guidelines related to the environment and public health and safety. In addition, the applicant must agree to provide compensatory mitigation to make up for damage caused to the streams it plans to impact. This mitigation can either be done on-site, off-site, or the operator can purchase credits from a mitigation bank that undertakes specific mitigation projects.

E. Challenges Exist in Protecting Human Ecology from the Impacts of Coal Mining, Despite Existing Regulations

While the coal mining industry is heavily regulated, several challenges exist in protecting human ecology. First, despite the success of the Abandoned Mine Lands program in reclaiming abandoned coal mining operations, millions of Americans still live less than one mile away from abandoned coal mines. According to OSM, $4 billion worth coal-related abandoned sites that are classified as High Priority for health and safety are awaiting reclamation.

In addition, despite laws and regulations in place that are designed to protect the environment and public health and safety, enforcement of mining laws and regulations has been problematic in some instances in Kentucky. Several cases of inspectors who knowingly allowed coal companies to violate the law, and were paid handsomely by coal companies to do so, have recently come to light.

In another incident in 2010, environmental groups discovered that Frasure Creek Mining and IGC Coal falsified thousands of pollution violations in reports submitted to the regulatory authority, the Kentucky Energy and Environment Cabinet. Initially, the Cabinet attempted to enter into a "slap on the wrist" settlement agreement with the company. However, environmental groups intervened and ultimately, five years later, worked with the Cabinet to finalize an historic settlement that effectively bars Frasure Creek from further mining in Kentucky.

Although the Frasure Creek case ultimately resulted in a settlement that citizens felt adequately punished the coal company for its wrongdoing, it is clear that continuing budget cuts and other issues have left the Cabinet unable to effectively enforce the law. In hearings related to the Frasure Creek lawsuit, state officials cited continued budget cuts as an impediment to adequately managing personnel and programs. Indeed, the Cabinet employs fewer people today than it did in 1990 and has more responsibilities.

Judge Phillip Shepherd, who presided over the Frasure Creek case and was formerly the Secretary of the Energy and Environment Cabinet, stated in a legal opinion that "with only a handful of enforcement personnel and a dwindling number of

field inspectors . . . it is impossible for the Cabinet to effectively regulate permittees such as Frasure Creek who systematically violate the [Clean Water Act].”

In addition to inadequate enforcement and budget issues, technology, information, science, and methodologies have improved since OSM last updated its regulations in 1983. In discussing its need for its recent Stream Protection Rulemaking, OSM noted that there is a need to ensure the regulators and permittees are using these advances in technology to adequately manage surface and groundwater hydrology, surface water runoff, and the restoration of streams, soil, and vegetation. Not only does new information exist on the adverse impacts that coal mining can cause, there have also been significant improvements in technologies and methods relating to mining engineering, stream restoration, and other methods and technologies relating to the “prediction, prevention, mitigation, and reclamation of coal mining impacts on hydrology, streams, fish, wildlife, and related resources. These advances have included significant improvements in cost-effectiveness and availability.”

IV. Opportunities to Limit the Adverse Effects of Coal Mining on Human Ecology

Several opportunities exist to confront the challenges Kentucky faces in improving public health and environmental impacts stemming from coal mining in the state. Adequate funding is crucial to cleaning up abandoned mine lands and ensuring that the agencies charged with protecting our land and water resources are properly staffed and equipped. President Obama’s Clean Power+ Plan would provide states and tribes $1 billion in funding over a 5-year period from the unappropriated Abandoned Mine Reclamation Fund. These funds would be used to reclaim abandoned mine lands and associated polluted waters while promoting sustainable redevelopment in economically depressed coal producing areas. Since many of the nation’s abandoned mine lands are located in Appalachia, there is a potential for Kentucky to benefit greatly from this proposal. The Power+ Plan also contains provisions that would strengthen the health care and pension benefits for coal miners and their families and provide funds to help Appalachian communities spur economic development as they transition away from an economy dependent upon the coal industry.

Additional opportunities exist to increase the budgets of state agencies, despite continuous budget cuts. Currently, the costs for processing most permit applications necessary to mine coal in Kentucky fall far short of the actual cost to the agency of processing the permit and completing required inspections. By raising the permit fees, the agencies can recoup the costs associated with these permits to increase funding. In addition, this would lead to the permittee’s customers subsidizing the full cost of permitting fees, instead of the current situation where Kentucky taxpayers are subsidizing the cost of obtaining a permit.

It is also imperative that when mining inspectors or coal companies violate the law, that the penalties assessed are high enough to deter future violations by not only the current violators, but also other potential violators. Where a culture exists that encourages instead of deters polluters to violate the law, human health and the environment inevitably suffer. As shown by the Frasure Creek case, where citizens become involved and work with the Cabinet, successful settlements adequate to deter future violations can be reached.

In addition to the Power+ Plan, the U.S. Office of Surface Mining recently proposed regulations that would provide a comprehensive overhaul to the current regulatory climate with a focus on increasing protections for streams and other waters, which would also protect human ecology. However, this rulemaking, called the Stream Protection Rule, has received harsh criticism from states and industry. Part of this criticism stems from the fact that in many cases it is difficult for stakeholders to work together because there is a lack of transparency and communication. For example, during the OSM rulemaking process, despite entering into a Memorandum of Understanding with OSM concerning the preparation of an environmental impact statement, eleven state agencies complained that they were given limited opportunity for involvement and were made to operate under such constrained timeframes that substantive involvement was impossible. As a result, several of these agencies withdrew from the MOU.

This results in a lack of trust between stakeholders and almost ensures that the federal government will not have buy-in from state agencies charged with implementing the rule. In proposing comprehensive regulatory reform, federal agencies must work closely with regulators and other stakeholders to ensure they understand the challenges states are facing and ensure the proposed regulations can be successfully implemented. In addition, where stakeholders are willing to compromise with each other, work together, and find common ground and begin this process at the beginning, the parties are more likely to emerge with a solution that is workable to all parties.

In addition to working together on rulemakings, one of the most promising areas in improving human ecology outcomes in Kentucky involves stakeholder collaboration on individual permits. Health impact assessments (“HIAs”) are emerging as an evidenced based tool designed to objectively demonstrate the costs and benefits of a particular land use decision (or other policy decision) on public health. HIAs systematically analyze a variety of data and consider input from stakeholders to determine possible effects of proposed project on the health of a community and makes recommendations on managing and monitoring those potential effects. HIAs can be part of an interdisciplinary approach to public health in coal mine permitting and could be employed similarly to environmental impact assessments and as part of the public interest determination already required to be made by the Corps of Engineers.

While no federal law exists that requires the use of health impact assessments in mine permitting, states are increasingly using health impact assessments and such assessments can be

done voluntarily. Alaska has used HIAs to evaluate mining operations and considers their use as a "best practice." In addition, The Appalachian Communities Health Emergency Act, a bill that would require health impact assessments in mining communities and prevent permit issuances in Appalachia until a determination that mining does not present any health risk to individuals in surrounding communities, was introduced in the U.S. House of Representatives in 2015. Thus, while HIAs will likely not be mandatory parts of mine permitting in the near future, citizens groups concerned about permits should work with the permitting authorities and the mining company and request an HIA as part of the permitting process. Such creative solutions can often be included in settlements related to permit challenges, as well.

Conclusion

Coal mining in Kentucky, while in decline, will continue to have impacts on human ecology. While challenges exist in protecting the environment and human health, improvements can be made where stakeholders engage in transparent and open communication early on in permitting and rulemaking processes. In addition, enforcement programs and the reclamation of abandoned mine lands are essential and can only be done with proper funding. Thus, while challenges exists and distrust and longstanding opposition exists between the parties, it is time to engage in meaningful dialogue and practices to address this important concern.

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The Wonder of Natural Life in Kentucky

Ronald R. Van Stockum, Jr.

A Cicada, Kentucky's Locust.

Introduction

During the age of European settlement of Kentucky, colonists from the East discovered the wonders of a land new to them, though previously inhabited and managed by Native Americans. Kentucky is a verdant state, lush in its heat, humidity, and rainfall. The diversity and abundance of life was immediately evident to all who came here. In fact, the region was so romantic to the burgeoning population of the eastern colonies, that literature of the time often equated the name "Kentucke" to mean "Paradise." Indeed, Kentucky is a paradise when one studies the efflorescence of life that inhabits this place. Life associating in complex communities within the varying ecological niches that the ancient land surfaces provide.[1]

The great glaciers of past ages came close to Kentucky, but did not significantly cross its borders. Except for a thin strip in the Northeast, Kentucky's land was not disturbed by those ice colossuses. The land surface here is as it was originally laid down, sediments mixed with life's detritus in the beds of ancient oceans and lakes. These beds were subjected to temperature and pressures until exposed to the forces of erosion. That erosion has been relentless since the oceans abandoned Kentucky more than 280 million years ago. The river-cut gorge of the "Palisades" of the Kentucky River in Central Kentucky exposes the oldest rocks we see on the surface of bedrock in Kentucky.[2]

That is a lot of time for nature to have carved out its varying niches for the diverse life of Kentucky to inhabit. And just as much time for evolutionary processes to develop new life forms capable of doing so. When the European settlers came to Kentucky, they discovered that the great diversity of life here was due not only to the ancient age of its landforms and its abundant rainfall, but also to its placement geographically on the continent. Floral and faunal elements from the North, South, East, and West come together here to mix. Kentucky truly is a "border state," when we consider the realms and kingdoms of life. And within the creeks, cracks, and crenulations of its landforms, there is quite a tale to tell.[3]

One can take a brief survey of life in Kentucky to obtain a sense of the wonder that can be found in the Commonwealth. With a little bit of study and a keen sense of observational hunting, one might find that unusual plant, Vittaria appalachiana, called the "Appalachian Gametophyte."[4] This plant represents the small gametophytic generation of a mostly tropical genus that alternates reproductively with a strap-like, epiphytic fern form, the sporophytic generation. In Kentucky, it is found as a fleshy thallus, a small liverwort-sized growth. The Kentucky species has freed itself from its sporophytic form, which does not grow in Kentucky. The Appalachian Gametophytes grow only in deep

A Black Snake Climbing.

Bad Branch Falls on Pine Mountain in Kentucky.

crevices of caves or behind waterfalls. The delight in identifying the Appalachian Gametophyte makes botanical exploration in the wilds of Kentucky's cliffs exhilarating.

If one jumps in a canoe and floats down the Green River of Central Kentucky, she will undoubtedly see freshwater mussel shells strewn on the bank. If one is lucky, she will find a muskrat "midden," where hungry muskrats have swum down to the river bottom and collected their tasty favorite meals. In those piles of discarded shells, one might find such exotic mussel species as the Monkey Face or the Purple Pimpleback.

It does not take much research to learn that the Green River of Kentucky is one of the centers of mussel (unionidae) evolution in the world, and that at one time there were more than 70 species of mussels extant in the river. Now, through the preservation efforts of such groups as the Kentucky Chapter of the Nature Conservancy, many may still be found there. And it does not take much to learn and memorize the shapes of a couple of dozen.

The Rattlesnake Fern. Its oil rich spores were collected and thrown in fires during magic shows.

With that exercise accomplished, a float down the Green River of Kentucky is like entering a three-dimensional kaleidoscope, with the identified shapes of mussel shells on the bank seeming to leap into one's vision upon their recognition.

If one decided to study the small rodents in Eastern Kentucky and the migratory patterns of their population, one might set small traps within the grasses on terraces beside streams or in fallow fields. Upon return, one would be surprised to discover the diversity of rodents scampering between clumps of grass. And then, slowly, the story of the Bog Lemming in Kentucky becomes clearer.[5]

One might walk up the banks and giant sloughs of the Ohio River as it flows from the northeast, forming the northern boundary of the Commonwealth of Kentucky. Looking within the bottomland hardwood forest, among the sloughs, one might find the Pecan Tree and note the farthest northern extension of that southern tree as it sneaks up the Ohio River Valley.[6] Look closely at the Buckeye in the old oxbow. See and feel the fine, lush, whitish under-leaf hairs. Look up at an ancient massive basswood. The undersides of its leaves flash sheets of white in the wind, exposing the tiny white hairs. These two trees, the Yellow Buckeye and White Basswood, are indicator species of the Mixed Mesophytic Forest described by E. Lucy Braun in the Cumberland Plateau of Kentucky, and discussed in more detail later in this paper. We see, in this oxbow, exciting elements of that forest migrating west and north after the retreat of the glaciers.

Travel to Mammoth Cave National Park and one can explore the longest human-surveyed cave in the world. But if one looks at a map, he would see that those caves lie south of the Green River of Kentucky, and that there is much more of the park lying just to the north. There one finds the heavily wooded and vegetated valleys of First Creek, Second Creek, Bylew Hollow and Cubby Cove. Cubby Cove is small enough to do a complete floristic survey. One might, with a colleague, be able to wander within that "space capsule of life" and note the many interesting and almost exotic forms of life living together in great diversity, isolated in the northern reaches of that famous park.[7] And the presence of disjunct populations of the Eastern Hemlock Tree might lead one into further inquiry.[8]

Explore the sandstone overhangs of the Dripping Springs Escarpment in Western Kentucky and you might discover the feathery, elusive Appalachian Filmy Fern.[9] And one would be surprised to find that same shy fern in a makeshift campsite overlooking the Kentucky River between the towns of Jackson and Beattyville, where one can sample the biota of Eastern Kentucky from a canoe.

Join with friends and canoe along the Kentucky River within its Palisades in Central Kentucky. One might come upon a large branch sticking into the water with a basketball-sized growth of a jelly-looking substance clinging to it. Quick research will identify that ball as a freshwater bryozoan, an uncommon life form in the Commonwealth. It would be an exciting find considering that so

many of our limestone fossils consist of ancient forms of these "moss animals" widely represented in the geologic record for hundreds of millions of years.

A Hemlock Tree growing on a sandstone cliff in Bylew Hollow.

A Snapping Turtle crossing the road in Shelby County, Kentucky.

Join a group of students seeking out amphibians and reptiles and travel throughout the Commonwealth identifying the different forms of frogs, toads, salamanders, snakes, lizards, and turtles in their natural range and habitat. Those diverse groups of organisms are abundant in Kentucky. The frequency of road kills causes the public to dismiss these organisms as being ordinary, insignificant, and otherwise uninteresting. In fact, their homes, habitats, and lifestyles are exceptionally curious and engaging. Just ask a Snapping Turtle crossing the road why he does so. Or sit by a pond or puddle in Spring, and smile at the activity coming to life around you.

One can learn to distinguish the poisonous snakes of Kentucky from the nonpoisonous snakes. It is a surprise to discover how some of the nonpoisonous snakes in Kentucky give the otherwise docile venomous snakes a bad name. Some of the nonvenomous snakes in Kentucky, such as the Black Water Snake, do earn the moniker, "mean as a snake," and some, such as the Black Racer, will advance on the unwary. Then there is the nonvenomous Hognose Snake, which will coil up threateningly, flatten its head, and wiggle its tail in dead leaves to sound like a Rattlesnake. If this fails to deter one's inquiry, the Hognose will roll over and play dead. Go ahead and turn him over. He will just roll back, belly up.

The snowflakes begin to fall gently like feathery clumps of white flour on the mile-long trail to the Falls at the Bad Branch State Nature Preserve on Pine Mountain. Soon, one crosses the creek and moves into the snow pillow cloud hanging in the high boulder-strewn valley. And there it is. Sixty feet high, a sheet of water fanning out and breaking into crystalline strings, singing thunder to the quiet floating flakes cloaking the valley in a white snow quilt. Bad Branch Falls. Majestic Hemlock Trees, translucent Indian Pipes, High Bush Blueberries, and Painted Trilliums. A 2,639-acre preserve, a state-designated wild river, and the call of the Raven. Send down your family to challenge the mist and raise your fists in salute.

As a group canoes down the Rockcastle River of Southeastern Kentucky, they will come to a boulder-strewn constriction in the river around which they should portage. How pleased and satisfied is one to see the rare Kentucky Lady Slipper, poised with its proud, rounded floral bucket, announcing its presence for everyone's pleasure as they pass, just as if it was ringing a joyous yellow bell.

Driving across the state to sample these habitats, one can pull out old historical records and follow the buffalo trails that used to penetrate into Kentucky from the Prairie Peninsula extending from Indiana and Illinois. Finding these buffalo routes is not difficult since the major pioneer roads tended to follow them. But the habitats created by thousands of buffaloes in their passage to Kentucky prairie fields and salt licks allowed for the expansion and distribution of a rare and endangered species of plant, the Running Buffalo Clover. One can find other endangered species at Blue Licks State Park Nature Preserve, one of the prime watering attractions for the buffalo in times past.[10]

And who would think that there are cold water habitats in Kentucky that contain the red algae, Batrachospermum? Red algae flourish in the oceans and along the coasts, but here they thrive in cool fresh spring water. Long-branched, string-like filaments that sport bunches of short, whorled branchlets. Batrachospermum can be found in Doe Run in Meade County, Kentucky. There, in a surprising and unique environment, life forms live out an isolated existence in a perfect home for their liking, carved from the unique lands of Kentucky.[11]

What a surprise if one scuba dives in Laurel Lake in Eastern Kentucky. In those pristine waters, one can see small freshwater jellyfish the size of a quarter. These curious creatures are not considered to be native here, but are still unique. They undergo reproduction through an alternation of generations where the jellyfish, the medusa form, reproduces sexually into the polyp form. That smaller, sedentary polyp will then reproduce asexually, budding off the medusa, which grows into the free-floating jellyfish with which you swim.

To complete this interesting survey, return to Louisville. Now the home of a metropolitan area of almost one million people, it was before European settlement a vast wetland forming an important flyway for migrating birds. One can drive down River Road and walk through the Caperton Swamp Preserve. He can smell the vegetation, feel the boggy soil and see the pools of water that contain a plethora of life forms in its algae, protozoans, aquatic plants and insects, amphibians, and birds.

This is Kentucky. It is, indeed, a place of wonder.[12]

A winter fox in Shelby County.

Kentucky's "Peace Eagle," the Vulture.

Diversity in the Past

The majority of Kentucky's land surface has been continuously devoid of ocean coverage since the middle Permian Period approximately 280 million years ago. Prior to that time, a long rift basin that would become Kentucky was uplifted in a long buckling arch. The Earth's great tectonic plates were colliding and raising up the early Appalachian Mountains as high as the Rocky Mountains. It is this uplift, which we call the Cincinnati Arch, that allowed for a more vigorous erosion of the heights along the arch. This cut into older strata risen up within the level of the erosion's reach along the arch. The Cincinnati Arch has two high spots, one centered in Lexington, Kentucky, and the other at Nashville, Tennessee. Rocks exposed along that line between the two are the oldest rocks, geologically speaking, exposed in Kentucky. As one moves either east or west of that line, the bedrock surface becomes younger in geologic age.

Life was rampant in the oceans covering Kentucky during this formation of what would become Kentucky's bedrock. Having burst out in diversity and abundance during the earlier Cambrian Period, the abundance of life began leaving significant evidence of itself in the sediment raining down on the ocean floors. It was in the Cambrian Period that numerous oceanic life forms developed shells using phosphates and calcium carbonates to protect themselves and in which to live out their lives.[13] The rain of these dead organisms falling to the bottom ocean muck left many impressions describing the types of life forms and, to some extent, the lives they lived. So for each geologic era, one can trace the panorama of evolving life as it unfolds in the geologic record.

The Ordovician Period followed the Cambrian Period 480 million years ago, and life in the oceans covering Kentucky was vibrant. Corals, sponges, and bryozoans were abundant in the shallow tropical seas. Trilobites crawled over an ocean floor beset with brachiopods, snails, and clams. Crinoid "sea lilies" waved in the ocean current where squid-like cephalopods and long, coned

nautaloids swam. Continents were low in elevation, resulting in less sand and silt from erosion. Sediments were primarily limestone, composed of calcium carbonate contained in the shells and skeletons of dead organisms or precipitated out from the oceans themselves. This strata outcrops in the Bluegrass Region of Kentucky where large slabs of fossiliferous limestone may be found in its creek beds.

In the Silurian Period, the Earth was warming due to the "greenhouse" effect of its atmosphere. Seas covering Kentucky were warm and shallow within which a proliferation of jawed and bony fish swam. Sea scorpions and worms lived around expanding coral reefs. The first primitive plants ventured out on land in this period, perhaps even onto islands in Central Kentucky. These rocks now surface in the Outer Bluegrass Region.

What scientists have described in popular literature as the "Age of Fishes" is the Devonian Period so well exposed at the Falls of the Ohio River across from Louisville, Kentucky. During this time, fish in the oceans underwent a great diversification. Vascular plants began spreading on dry land. Tetrapods began their climb out of the sea toward the evolution of land animals. Today, there are very few fish fossils actually found, but fossil mounds of sponge-like stromatoporoids, brachiopods, bryozoans, and crinoids can be observed at the Falls.

It is important to remember that we see only glimpses of this long past record of Kentucky ocean life. It is expressed in the bedrock only after shells and skeletons fell as detritus into the sediment at the bottom of the sea. Those oceans once covered the entirety of Kentucky and teemed with life that could swim through the ocean from one end of the state to the other. Not all of these life forms are well represented in the fossil record, and the soft-bodied organisms hardly at all.

In the late Devonian Period, oceans deepened over Kentucky. In the absence of light and oxygen, thick beds of black shale were accumulated. The "black shale" at the base of Muldraugh Hill is of Devonian Age, with the oil and gas trapped within demonstrating the great expansion of life in this period.

The next youngest period of geologic time represented in Kentucky rock is what we call the Mississippian Period. It forms the bedrock in an area of Central and Southern Kentucky that we call the Mississippian Plateau. It is a region often referred to as the "Pennyrile," named for a plant, the American False Pennyroyal, which is common there and which reminded the settlers of the Pennyroyal of Europe. Massive limestone beds are abundant in the middle of the Mississippian Period. Later in the period, the expansion of coastal plains and deltas feathered in muds and silts over parts of Kentucky.

During the end of the Period, erosional forces acting on mountains west of Kentucky laid down great beds of sand in the center of our state, forming the Big Clifty Sandstone of the Dripping Springs Escarpment. This sandstone cap is what enabled the great limestone caverns of Mammoth Cave to form and survive for so long in their "mammoth" proportions. The Big Clifty Sandstone forms a roof and erodes much less quickly than the limestone underneath. For more than five million years, water has squeezed through cracks in the sandstone, entered into the limestone below, and dissolved away the caverns.

The Mississippian Period is also known as the "Age of Crinoids." These animals, related to starfish, grew on extended stalks, their tentacles waving in the ocean current like "sea lilies." Crinoid "columnals," sections of its "stalk," are often found in eroded rock. If one is lucky and looks carefully, she may see the starfish pattern in the center of a section. Put that one in your pocket.

Their cousins, the blastoids, never fail to satisfy when one of their nut-shaped "heads" is pulled out of shaley rock, revealing the 5-part ridges of its structure.[14] But it is the corkscrew bit shape of the bryozoan Achimedes that quickly draws one's attention to rock. They are rare, but amphibian fossils of the "Embolomeri" are also sometimes found in rocks of Mississippian Age.

The next geologic period in Kentucky is of particular importance in the economic history of the Commonwealth, for it contains the great coalfields of Eastern and Western Kentucky. These are the rocks of the Pennsylvanian Period and represent the vast, marshy, swampy coastal areas of land that formed as Kentucky began to finally rise out of the sea. As the oceans alternately withdrew and re-flooded Kentucky, the great coal forests reigned supreme in the swampy muck of forming land. This period is known as the "Age of Coal."

These great coal forest deposits contain the compressed and altered organic compounds from tissues that made up those plants. Oftentimes, glimpses of this great forest can be seen in tree bark patterns or imprints of fern leaves in the shale beds associated with the coal or within the coal seams themselves. Large "ham hock" sized blocks of stone will appear pimpled with the bark pattern of the extinct lycopsids Sigillaria or Lepidodendron. Those tree-sized plants no longer exist, but at one time towered more than 100 feet above the marshy surface in which they grew, with trunks greater than three feet in diameter.

The seas have not returned to Kentucky since the Pennsylvanian Period, and the process of erosion has removed those rocks from the center of the Commonwealth. Throughout those millions of years, bedrock has crumbled and mixed with decaying dead plant tissue to slowly form regolith and the rich soil for which Kentucky is so famous.

There are no dinosaur fossil deposits that have been found in Kentucky. But surely they roamed the land, as did all of the early mammals and other life forms dominated by the giant animals that evolved in the Mesozoic Era known as the "Age of Reptiles." There are still, however, descendants of the ancient plant kingdom that once filled out Kentucky's landscape during that time.

It is not often that one stops to look closely at the nonvascular plant world of the bryophytes, liverworts, and lichens. But thousands of their species are still extant worldwide. If one looks carefully in moist areas on stones along shaded creeks, he may find the dioecious common liverwort with its distinctive "gemma cups," asexual fruiting bodies. For many, the cool, crisp liverworts covering mossy, moist stream rocks bring forth images of Christmas.

How often have people stared at the soft-looking mats of moss cloaking fallen logs in the forest, fruiting bodies held aloft like dark street lamps? Look carefully and one might see the British Soldier Lichen with its red-capped helmet. These lichens are symbionts, two organisms living in a mutualistic association. In the case of this lichen, one is a fungus and the other a green algae.

The oldest vascular plants still extant are the Lycophytes, which first appeared more than 400 million years ago. For 40 million years, they were the dominant form of plant life. About 1,200 species survive today, mostly in the tropics. The few in Kentucky are small and are often called "Ground Pine," "Club Moss," and "Ground Cedar." They look like large mosses or pine seedlings. It is delightful to remember that they are living fossils, descendants of the great coal forests of Kentucky.

There are at least 20,000 species of ferns and fern allies worldwide. In Kentucky, they number 73, occupying habitats generally under environmental stress, which allows them to compete favorably with the more advanced flowering plants. Ferns evolved early in the Age of Dinosaurs, 360 million years ago in the Mesozoic Era. As part of the great coal forest in the Pennsylvanian Period, they grew as high as 80 feet.

In the great coal forest, there was also Calamites, a giant tree-sized horsetail. There is only one genus of horsetails left worldwide with around 30 species. Today, one can find the "Scouring Rush" and the "Field Horsetail" along Kentucky's roadside ditches in weedy clumps. Pioneers used the scouring rush to clean pans after cooking. The author still does.

Gymnosperms were next to evolve in the vascular plant kingdom, and the cone-bearing conifers still maintain a striking presence with 700 extant species worldwide. They have a strong vascular tissue, allowing the movement of nutrients, water, and sugar up great heights to the small male cones releasing windblown pollen to the sticky large female cones below. These conifers remain healthy competitors in our forests today. In Kentucky, they include Pine, Hemlock, Cypress, Yew, Cedar, and Juniper. Their leaves are generally needle-like or scale-like. Because of the lower surface area to volume ratio of their needles, and less water contained within, they generally retain their foliage in winter and protect their tissue from freezing temperatures with cellular "antifreeze."

In Kentucky, one may also find planted "Maidenhair Trees," a genus that first appeared in the fossil record 300 million years ago. Only one species survives, the Ginkgo Tree. In fact, this tree was only known from the fossil record until rediscovered in monasteries in China. The trees are dioecious with fruits of the female tree releasing a fleshy seed containing butyric acid. When the fruits are crushed, they smell like vomit or rancid butter. These trees were planted in the development of St. James Court in Louisville in the late 1800s. It is a unique experience to walk among the Victorian mansions in Fall, crushing the "berries" under foot.

In time, the dominance of conifers was to be successfully challenged by plants with more efficient systems of gathering light. These new plants had also developed more effective strategies of reproduction, including the use of flowers and evolving insect species to aid in their reproductive strategy. These are the magnificent Angiosperms, flowering plants with more than 250,000 species currently identified across the world, and with many more yet to be catalogued. In Kentucky alone, there are more than 2,600 species of vascular plants, 78% of which are native.[15]

The geographic crossroads that represent Kentucky have allowed a great flourishing of plants and represent one of the great natural resources of the Commonwealth, its flora.

The Geography of Kentucky

Kentucky is an ancient land surface barely touched by the periods of glaciation that smoothed out so much of Ohio, Indiana, and Illinois. In fact, the Ohio River is an "artificial" river system created by the damming of north-flowing rivers by massive mile-high glacial walls spreading south from the Arctic. The impounded rivers formed lakes that overflowed to the southwest and carved a new channel, the Ohio River.

The Ohio River contributes a greater amount of fresh water to the Mississippi River where it joins at Cairo, Illinois, than the Mississippi River itself. The storm clouds that winds bring up from the Gulf of Mexico release 40-50 inches of rainfall annually to the Commonwealth. As a result, there are more miles of running water in Kentucky streams than in any other state in the country, save Alaska.

As previously noted, the land mass that forms bedrock in Kentucky is composed of rock formed from sedimentary deposits. It was laid down over hundreds of millions of years as sediment and dead organisms fell onto the floor of the oceans that once covered Kentucky.

The composition of these sediments varied according to the depth and temperature of the oceans, their variable retreat and encroachment, the life forms abundant within the ocean, and the contribution of eroded minerals, sands, and clays from mountains to the east and west. These sedimentary rocks were laid down in a "layer cake-like" fashion, one strata on top of the other.

Depending on the nature of the material deposited, one could find calcium carbonate limestone; dolomite, which is limestone

with a higher concentration of magnesium; shale, which is composed of fine layers of muddy sediment; coal beds, which contain compressed organic material formed in swamps and peat-like conditions; and sandstone, representing the erosion and deposition of igneous and metamorphic sand grains from areas surrounding Kentucky. As mountain chains were uplifted by tectonic activities, erosion became more aggressive.

What makes Kentucky so interesting is that these layers were laid down consecutively one on top of the other, with the oldest toward the bottom and the youngest toward the top. Originally, they appeared flat in cross section, like a stacked series of plates. In Kentucky, they no longer appear so everywhere. Because of the nature of geologic movements, tectonic forces, and geologic hotspots, there has been a warping of these beds, evident by the angle of the bedding planes one sees as she drives through road cuts on a Kentucky highway. In some areas, faults in the rock have formed with some sections sinking and others thrust upward.

One of the most prominent examples of this warping in Kentucky is the "Cincinnati Arch," formed during the Paleozoic Era as continental land masses collided and formed the super continent "Pangea." After the seas departed and the rocks were elevated higher, they eroded more vigorously, exposing the older rock layers below. That is why the oldest sedimentary rocks exposed in Kentucky are found in the Inner Bluegrass area surrounding Lexington, Kentucky, the area that lies on top of the raised arch.[16]

The Sally Brown Nature Preserve, the Dupree Nature Preserve, the Crutcher Nature Preserve, and the Earl D. Wallace Nature Preserve lie on the old rock exposed on the arch along the great Palisades of the Kentucky River.[17] There are no state parks in this magnificent corridor of the Kentucky River. Private philanthropy and conservation has stepped forward to preserve this part of our heritage. Here, towering limestone cliffs support a wealth of life, including the Yellowwood Tree. Walk among 25 species of mammals and 35 species of reptiles. Look down at the unbroken ribbon of forest along the river that supports populations of the Gray and Indiana Bats. Learn to identify the smooth Yellow Buckeye from prickly Ohio species and sense the link to the Mixed Mesophytic Forest of mountains to the east.

As one travels east or west from Lexington, he traverses younger rocks, periodically meeting a zone of transition where the next highest strata of bedrock is more resistant to erosion than the one just crossed. At this point, erosion by wind and water will create a hill where a one-sided slope or cliff must be climbed to reach the top of the next strata. The rise is called a "cuesta," and the surface above, a flat or dissected "plain." Cuestas are prominent features in Kentucky. They occur throughout the Commonwealth and are geographic guides to one traveling within.

As one moves east from the Inner Bluegrass, they cross to the Outer Bluegrass, the Highland Rim, and the Pottsville Escarpment, finally rising onto the Eastern Coal Fields of the Cumberland Plateau. Deep in the Buck Creek Gorge, cutting into massive limestone at the edge of the Cumberland Plateau, are caves. More than ninety of them feed pristine fresh water into the river and support 77 species of fish and 30 species of mussels, including the endangered species, Cumberland Bean Pearly Mussel. Feel the cool in the air as one canoes past the cave openings, swirling through the misty fog condensing there. Watch the patterns of aquamarine-colored water, mixed into patterns like liquid sand paintings. And that sunflower on the rocky, sandy bank to your right, might it be the tasty Jerusalem Artichoke?

At the southeastern border of the Commonwealth, one encounters the long block of bedrock violently thrust upward that we know as Pine Mountain. Rising to 3,273 feet above sea level, it forms a 125-mile-long continuous wildland corridor that accommodates the migration of plants and animals as they move in elevation and latitude in response to climate change. The purchase, connection, and preservation of this wildland corridor are some of the primary efforts of the Kentucky Natural Lands Trust.

If one goes west from Lexington, the same general topographic rises are evident. As one moves from the Inner Bluegrass into the Eden Shale Belt around Frankfort, across the Outer Bluegrass and up Muldraugh Hill, he crosses successive cuestas. Muldraugh Hill is a cuesta, the isolated erosional remnants of which are called the Knobs, including such outliers as Louisville's Iroquois Park. Topping Muldraugh Hill, one travels across the Mississippian Plateau (the Pennyrile Plateau) and moves southwest to the sandstone- covered Dripping Springs Escarpment.

There are many "buzzard roosts" in Kentucky folklore, high cliffs above which swirl vultures eyeing out carrion meals. The Cherokee called them "peace eagles," for they never kill for food. Up on the Nolin River, just north of Mammoth Cave, there is such a place of sandstone-capped ridges and deep gorges. Looking across the gorge in winter, one will see a line of Evergreen Trees, undoubtedly cedars or pines.

Except they are not.

They are Eastern Hemlock Trees, disjunct from their main population to the east. Isolated pockets of a different assemblage of plants. How did they get here? How long have their ancestors inhabited this place? Umbrella Magnolia, Holly, Pawpaw, and Mountain Laurel clothe the slope. The Mountain Spleenwort, the Putty Root Orchid, the Spotted Pipsissewa, the Crane Fly Orchid, and the Downy Rattlesnake Plantain. These are out of place. Should they be here together? There is Stonecrop and Partridge Berry, Spice Bush, the Devil's Walking Stick, and Rock Club Moss. One might also find the Single-head Pussy Toe, Boott's Sedge, and the Cave Alum Root. What a special place. It is here, back in the darkness of the overhangs, that one will find the Appalachian Gametophyte. The Western Coalfields are next, part of the "Shawnee Hills."

There is a valley in Western Kentucky that has a special place in human history. Mantle Rock, with its massive sandstone arch,

was home to ancient Kentuckians. It is the only natural arch in Western Kentucky and, east of the Mississippi River, the largest freestanding arch. On top of the arch are shallow soils and mats of lichens and moss. It is a rare environment, a glade. Scattered within that glade, one finds Prickly Pear Cactus. It was at this place that 1,766 Cherokee camped during the winter of 1838. They waited here for the Ohio River to thaw and when they would again be forced to move west on the "Trail of Tears."

Just beyond, another unusual geologic area is encountered in the Flourspar District. Here sills and dikes of igneous mineral intrusions broke through the Earth's crust during the Permian Period and filled up cracks in the rock to reach the surface.[18] Continuing past the Flourspar District, one drops back down onto the Mississippian Plateau, soon reaching the fascinating part of Kentucky called the "Land Between the Lakes."

In this area, two great river systems, one of which, the Cumberland River, drains areas as far east as Pine Mountain, Kentucky. The second, larger and most southern of these two rivers, the Tennessee River, drains a geographic region so abundant with running water that it became the focus of giant energy-generating hydroelectric dams and power plants administered by the Tennessee Valley Authority. The two rivers come within several miles of each other to discharge their waters into the Ohio River just above Paducah, Kentucky.

Beyond the Mississippian Embayment section of Kentucky is an area we call the "Jackson Purchase." There, in Marshall County just outside Calvert City, is Cypress Creek Swamp. One can canoe the black water, stop with his children to climb a beaver dam, or look overhead at the wonderfully rare rookery of Great Blue Herons. Float through this Kentucky Nature Conservancy Preserve and run your fingers on the knees and bark of the Cypress Tree and Water Tupelo. See the snake that is swimming in the water past the canoe. Is its head held erect above the water as it swims? Go to Murphy's Pond in the Obion Creek State Nature Preserve and find out.

Up along the Ohio River in Northern Kentucky are rocks of a strange conglomerate gravel. It is hilly land, not layered in bedrock. Cliffs are as high as 40 feet. These are remnants of the Glacial Ages, when bulldozing sheets of ice swept down from the north. Seven hundred thousand years ago, melting waters from these glaciers swept gravel outwash into Boone County, cementing them into those cliffs. Walk among the Maple, Basswood, Birch and Oak in this moist environment. Be sure to spy out the Red-backed and Dusky Salamanders along the creeks and under the mull in this "Enchanted Valley."

Early Times

Kentucky was inhabited early by peoples that most probably came across the Bering Strait to populate a new continent. We know from their spear points that they were in Kentucky during the Paleo-Indian Period more than 9,000 years ago.

During the middle and late Archaic Period, 5,000 years ago, Native Americans were living in seasonal villages on the Green River of Kentucky and using large quantities of mussels found in the river.[19] They left large waste piles of discarded mussels called "shell middens," one of which, "Indian Knoll," covers several acres.

1,500 years ago, in the late Woodland Period, Native Americans were camping in Shelby County, Kentucky, feasting on at least 25 different species of animals, including White-tailed Deer, Black Bear, Raccoon, Turkey, Gray Squirrel, Skunk, Beaver, Wolf or Dog, and Turtle. Plants such as Squash, Locust, and the nuts of Butternut, Hickory, and Walnut were also gathered.[20]

Those early times in Kentucky were investigated by W.D. Funkhouser and W.S. Webb of the University of Kentucky. In 1924, Funkhouser published investigations into Kentucky's biodiversity, entitled "Wildlife in Kentucky."[21] In 1928, Webb and Funkhouser published "Ancient Life in Kentucky," describing their extensive work in the Commonwealth.[22]

In Eastern North America, the gathering of foods evolved into the cultivation and breeding of nutritious, edible plants. These "garden" crops supplemented the harvesting of naturally occurring foods such as Pecans, Grapes, Wild Rice and Maple Sugar. The domesticated seed crops included Squash, the oil-rich seeds of Sunflower and Sumpweed, and the starchy seeds of Goosefoot, Little Barley, and Erect Knotweed.[23]

These cultivated plants are often referred to as the "Eastern Agricultural Complex." But 1,000 years ago, a temperate hardy strain of corn from Mesoamerica arrived with Mexican beans and squash. They are often referred to as the "three sisters" and quickly supplanted the previously domesticated plants in the Native American diet. Now those first cultivated food crops are lost or relegated to the status of weeds.

One of the earliest and most colorful of the scientific explorers of Kentucky was Constantine Samuel Rafinesque. Born in 1783 in Turkey, he traveled down the Ohio River in 1818, where he befriended the great American naturalist John James Audubon, then residing in Henderson, Kentucky. From 1819-1826, he was a professor of botany at Transylvania University in Lexington, Kentucky, the first institution of higher learning west of the Appalachian Mountains.

Rafinesque had an insatiable appetite for exploration and the discovery of uncatalogued life forms in the frontier. He published more than 200 articles and named over 6,700 plants new to science. Few of Rafinesque's classifications, however, have survived in modern usage.

Biodiversity in Kentucky

Kentucky is blessed with a wealth of life.[24] Many of us are familiar with the large forms of life that grace our lawns as trees and shrubs on which alight our colorful species of birds. We have

seen the trophy mammals and fish that adorn our many walls. And we long for the sight of our Spring wildflowers bringing renewed youth into our lives. But worldwide, more than 60% of species that have been identified are insects. Of the identified insect species, beetles are worldwide the most numerous.

There are more than 90,000 species of insects in North America. It is estimated that more than 15,000 are found in the Commonwealth, with many more waiting to be discovered and catalogued.[25] The order Lepidoptera (butterflies and moths) is well represented and ably described by Dr. Charles V. Covell, retired from the University of Louisville. Of the approximately 2,400 species of Lepidoptera in Kentucky, more than 2,300 are species of nocturnal moths.

It is surprising to some to learn that of the almost 1,300 worldwide species of scorpion, there is one, the Southern Devil Scorpion, that is found in Kentucky. In the 1970s, one of the author's graduate student classmates at the University of Louisville proposed a master's thesis wherein he would collect and allow himself to be bitten on the arm to test the scorpion's toxicity. He never did and decided instead to go into the banking industry.

Roger's Cave Beetle can only be found in Kentucky, and only in one cave. Because of its abundant karst topography, Kentucky has a wealth of subterranean beetle species. Of those 59 species identified in Kentucky, greater than 90% are endemic, meaning only found in the Commonwealth.

Two-hundred-and-forty-five species of fish and lamprey have been historically identified as native to Kentucky. That is approximately 30% of the North American total, and greater than that found in any state other than Tennessee and Alabama. In addition, 23 nonnative fish have been introduced into the Commonwealth, many for sport fishing.

All of Kentucky's amphibians are native. Represented by 53 species, 20 are frogs and toads, and 33 are salamanders. Approximately 26% of the nation's salamander species are found in Kentucky. All but one of Kentucky's 55 reptilian species are native, and include 14 turtles, 9 lizards, and 32 snakes.

The avian fauna of Kentucky is also rich, with at least 377 species of birds having been recorded here. Two-hundred-and-seventy-five species are regularly found, with approximately 150 species nesting in the state. Some of Kentucky's most conspicuous birds, however, are imports. The Rock Pigeon, European Starling, and House Sparrow are Eurasian species, while the House Finch is from the Western United States.

Bachman's Warbler and the Ivory-Billed Woodpecker formerly inhabited the bottomland forests and swamps of Western Kentucky and are now extinct. The Carolina Parakeet and Passenger Pigeon are also extinct, previously represented by massive populations within the Commonwealth of Kentucky. The Greater Prairie Chicken was once found throughout Kentucky's prairie land, but is now rare throughout its North American range and extirpated, meaning absent, in Kentucky.

There are 71 species of mammals in Kentucky, four of which are not native. There is one marsupial (the Opossum), one armadillo, 10 shrews and moles, 16 bats, three rabbits, 24 rodents, 12 carnivores, and four hoofed ungulates.[26]

Five-hundred-and-seventy species (approximately 24%) of Kentucky's flora are nonnative. The Kentucky Exotic Plant Council describes 92 of these species as invasive concerns for Kentucky's habitats.[27]

A number of accomplished biologists in Kentucky have explored the great diversity of life in the Commonwealth. During the late 1700s, the botanist and possible French government agent, Andre Michaux, traveled extensively through Kentucky. His son, Francois Michaux, followed him in the early 1800s. Later in the century, Charles W. Short and Sarah F. (Sadie) Price worked in Kentucky to identify and catalogue the different forms of botanical life existing here. A number of scholars and students of Kentucky flora and fauna have produced works describing life in Kentucky.[28]

Forests of Kentucky

In 1950, Dr. E. Lucy Braun, a Professor of Plant Ecology at the University of Cincinnati, published her highly influential book, "Deciduous Forests of Eastern North America."[29] She believed that forest structure evolved complexity along with the development of diverse topography created by the erosion cycle. Because of the ancient, unglaciated land surfaces of Kentucky, she studied often in Kentucky, especially in the complex forest associations in Eastern Kentucky.[30]

Dr. Braun described the assemblage of trees in the eastern mountains as the Mixed Mesophytic Forest, stating:

"The Mixed Mesophytic Association, which characterizes this region, is the most complex and the oldest association of the Deciduous Forest Formation. It occupies a central position in the deciduous forest as a whole, and from it or its ancestral progenitor, the mixed Tertiary forest, all other climaxes of the deciduous forest have arisen."

As such, Dr. Braun believed that the Mixed Mesophytic Forest of the Cumberland Plateau of Kentucky represented the most mature stage of forest development.[31]

From these ancient forest complexes spread components to colonize less mature topography and the newly exposed surfaces scraped clean by the retreating glaciers. Dr. Braun described these as "association segregates," elements of the Mixed Mesophytic Forest coming into dominance on these more exposed surfaces. Accordingly, in Kentucky we have the "Western Mesophytic Region," a transition zone in Western Kentucky. Locally, certain areas of the Commonwealth are dominated by Oak-Hickory or Beech-Maple forests.

Investigate and Secure

In 1976, during the Administration of Kentucky Governor Julian Carroll, the Kentucky State Nature Preserves Commission (KSNPC) was formed. It is an independent agency, which for administrative purposes is currently attached to the Kentucky Energy and Environment Cabinet. It manages more than 27,500 acres in 63 nature preserves and has 15 employees. The Director, since 1998, has been Donald S. Dott, Jr. It has a five-member Board currently chaired by Carl Breeding. 2016 will mark its 40th anniversary.[32]

The Nature Conservancy (TNC) is a national conservation organization founded in 1951. In the mid 1970s, the Kentucky Chapter of TNC was formed.[33] Hugh Archer became the Kentucky Chapter's first Director, serving from 1980 for eight years. During that time, TNC was instrumental in the preservation of the Bad Branch Falls on Pine Mountain. TNC studied the Kentucky River Palisades, began to protect Jessamine Creek Gorge, and worked to preserve sixteen areas of ecological significance in Kentucky, including Murphy's Pond, Dinsmore Woods, Mantle Rock, Swan Pond, Thunder-Struck Shoals, and Pilot Knob.[34]

Hugh Archer was followed as Director of the Kentucky Chapter of TNC by James Aldrich, who served almost twenty years in that capacity.[35] During that time, TNC worked to preserve significant lands along the Palisades of the Kentucky River, the Green River, the Rockcastle River, Horse Lick Creek and at Mantle Rock in Western Kentucky. An important and large addition to the Bad Branch Preserve was also procured by TNC.

One of the oldest conservation organizations in the country, River Fields, focuses on the Ohio River. River Fields has protected more than 2,200 acres in 37 properties. Meme Sweets Runyon is the longtime Executive Director.[36]

In 1992, Marc Evans, Botanist with the Kentucky Nature Preserves Commission, discovered the virgin, old growth trees at Blanton Forest while performing a helicopter survey of Pine Mountain.[37] In 1995, the Kentucky Natural Lands Trust (KNLT) was incorporated to begin the purchase and protection of Blanton Forest.[38]

After guiding the organization in its formative years, Hugh Archer became the Executive Director of KNLT in 2004. Marc Evans is currently Chairman of the Board of Directors. KNLT focuses on the reassembly of large forest tracts, defining intact migratory corridors prioritized by size, availability and rare species. Large projects currently include the Pine Mountain Wildlands Corridor and the Bernheim-Fort Knox Corridor. KNLT also manages eight preserves with rare species.[39]

Bernheim Arboretum and Research Forest manages 14,500 acres in the Knobs area of Kentucky south of Louisville. I.W. Bernheim, a Kentucky distiller, purchased the land in 1928, opening it to the public in 1950.[40] Camp Crooked Creek of the Lincoln Heritage Council of the Boy Scouts of America is situated adjacent to Bernheim Forest.[41]

The Kentucky Heritage Land Conservation Fund was created by the Kentucky legislature in 1994. It is managed by a 12-member board, six of whom come from government, and six from the private sector. The Fund receives monies from three sources: 1) environmental fines from cases dealing with air, water and waste in the Energy and Environment Cabinet; 2) the Kentucky Unmined Minerals Tax; and 3) Kentucky's "Nature's Finest" license plate. The Fund has protected numerous sites of biological significance in the Commonwealth.[42]

The Kentucky Land Trusts Coalition promotes "... excellence and sustainability in land trust programs..." This association provides ongoing seminars in support of conservation in Kentucky.[43] 21st Century Parks was established in 2005 and is performing outstanding service in Jefferson County. In addition, Western Kentucky University operates the Green River Preserve, which comprises more than 1,500 acres on the Green River.[44]

The Kentucky Department of Fish and Wildlife Resources (KDFWR) has a long history of conservation of both game and nongame animals. Earl Wallace was the first Commissioner in 1945, Tom Bennett was the fifth in 1993, and Gregory K. Johnson assumed the position in 2014. In 1944, the current organizational structure as an independent state agency was instituted. It is currently aligned with the Kentucky Tourism, Arts and Heritage Cabinet.

In the 1940s, KDFWR began the publication of the "Happy Hunting Ground" Magazine, changed to "Kentucky Afield" in 1992. The magazine has long featured the artwork of Rick Hill in "Nature Notebook." In 1995, the Salato Wildlife Education Center opened at KDFWR Headquarters outside Frankfort, Kentucky. Noted Biologist John MacGregor has long been associated with the nongame section there. MacGregor provided essential leadership in Kentucky regarding natural areas and biodiversity.

The Federal Government has been active in conservation activities in the Commonwealth of Kentucky. The United States Forest Service oversees more than 700,000 acres of land in the 2 million acres designated for the Daniel Boone National Forest of Eastern Kentucky. The United States Fish and Wildlife Service, with Lee Andrews as Supervisor of the Kentucky Field Office, is especially active in Kentucky, dealing with habitat, fisheries, endangered species, migratory birds, and wetlands. In addition, the Federal Natural Resources Conservation Service and the U.S. Army Corps of Engineers have been involved in important conservation activities in the Commonwealth.

Conclusion

There is in Kentucky a wealth of life within range of one's senses and reach. Although we often focus on the "big and the beautiful" forms of life (the giant trees, the bounding deer, flocks of ducks, and the newly returning brown bears), the greater diversity of life is smaller and forms a net, which wraps around us.

It does not take a modern Thoreau, or a poet like Wendell Berry, to hike in a forest, walk on a farm field, or sit on the banks of a river long enough to observe the abundance of life here. Recognition slowly forms, to those who allow it, of the beautiful and diverse forms of life that fill out the space in which we move. In fact, with a modicum of study to support the identification of that abundance, a colorful spectrum of busy life forms will reveal themselves. They move through time, just as we do. And they are living their lives out in Kentucky, just as we are.

The pioneers were correct. Kentucky is, indeed, a "Paradise."

Endnotes

1 Much of the data reported in this article comes from the detailed efforts of the Kentucky Nature Preserves Commission as described in their 2010 publication Kentucky's Natural Heritage, An Illustrated Guide To Biodiversity, edited by Greg Abernathy, Deborah White, Ellis L. Laudermilk, and Marc Evans (foreword by Wendell Berry), 2010, The University Press of Kentucky, Lexington, Kentucky. Further information can be obtained from the 2000 publication, Precious Heritage, The Status of Biodiversity in the United States, Bruce A. Stein, Lynn S. Kutner, Jonathan S. Adams, Editors, 2000, The Nature Conservancy & Association for Biodiversity Information, Oxford University Press, New York, New York. For a general overview, see the entries for Flora and Vegetation and Fauna by Ronald R. Van Stockum, Jr. in "The Encyclopedia of Louisville," John Kleber, Editor, 2000, University Press of Kentucky,

2 This is the area along the Kentucky River near Tyrone, where the famous "Kentucky River marble" and the "Birdseye" stone, both fine-grained limestone, were quarried.

3 See Kentucky, Naturally, the Kentucky Heritage Land Conservation Fund at Work, Thomas G. Barnes, 2013, Acclaim Press, Morley, Missouri. A further introduction into the biodiversity of Kentucky can be had by examining Dr. Barnes' 2002 publication, Kentucky's Last Great Places, 2002, The University Press of Kentucky, Lexington, Kentucky.

4 The genus Vittaria includes a group of neotropical epiphytic "shoestring ferns." The fern form is the diploid sporophyte, alternating in generations with its haploid gametophyte. The Applachian gametophytes exist in Kentucky without its sporophytic generation. The gametophyte reproduces asexually from a small lobe-like "thallus." They are often found in the back of sandstone caves and overhangs. Donald R. Farrar and John T. Mickel, Vittaria appalachiana: A Name for the Appalachian Gametophyte, *American Fern Journal*, Vol. 81, No. 3 (Jul. - Sept., 1991), pp. 69-75.

5 Thane S. Robinson, A Contribution to the Biology of the Southern Bog Lemming in Kentucky, 1981, Trans. Ky. Acad. Sci., 42 (3), 90-94.

6 Van Stockum, R.R., Jr. Corn Creek: Migratory Waystation for Woody Plants on the Ohio River, presentation to the Kentucky Academy of Science, 1975, University of Louisville.

7 Van Stockum, R.R., Jr. and Max Medley, Cubby Cove, an Example of the Big Clifty Sandstone Flora, presentation to the Kentucky Academy of Science, 1978, Richmond, Kentucky.

8 Van Stockum, R.R., Jr., 1974. Relic Populations of Tsuga Canadensis in Southern Indiana: Ecological Studies Relating to Their Origin. Master's Thesis, University of Louisville.

9 Ferns and Fern Allies of Kentucky, Ray Cranfill, 1980, Vol. 1, pg. 129, Kentucky State Nature Preserves Commission, Frankfort, Kentucky.

10 Julian Campbell, M. Evans, M.E. Medley, and N. L. Taylor, 1988. Buffalo clovers in Kentucky (Trifolium stoloniferum and T. reflexum): historical records, presettlement environment, rediscovery, endangered status, cultivation and chromosome number, Rhodora 90: 399-418.

11 W.L. Minckley and Donald R. Tindall, Ecology of Batrachospermum sp. (Rhodophyta) in Doe Run, Meade County, Kentucky, 1963, Bull. Torrey Botanical Club, Vol. 90, No. 6, PP. 391-400.

12 The author is reminded of the romance of Kentucky in reflecting on the journeys of the great naturalist, Alexander Von Humboldt: "Everywhere the reader's attention is directed to the perpetual influence which physical nature exercises on the moral condition and on the destiny of man. It is to minds oppressed with care that these pages are especially consecrated. He who has escaped from the stormy waves of life will joyfully follow me into the depths of the forests, over the boundless steppes and prairies, and to the lofty summits of the Andes." Views of Nature: Or Contemplations on the Sublime Phenomena of Creation, Alexander Von Humboldt, 1850, Author's Preface to the First Edition, Henry G. Bohn, Covent Garden, London, England.

13 Phosphates are concentrated in the Lexington limestone, accounting for as much as 10% by weight. It is thought that the phosphorous-rich soils of the Inner Bluegrass supported the breeding of strong-boned thoroughbred horses.

14 Before I-64 was paved in Crawford County, Indiana, the author and his major professor, Arland Hotchkiss, discovered a thin, shaley strata high on the new road cut. Here, in a layer only 2 inches in thickness, we could pull out blastoid heads like peanuts from a bag.

15 Ronald L. Jones, Plant Life of Kentucky, An Illustrated Guide to the Vascular Flora, 2005, The University Press of Kentucky, Lexington, Kentucky. 77 are Pteridophytes, 13 Gymnosperms, 1,767 Dicots, and 743 Monocots.

16 One can imagine the layer-like system of Kentucky bedrock as a series of thick paper plates. If one stacks these paper

plates one on top of another, bend them down the middle, and then take a pair of scissors to cut out a hole in the center, when it is unfolded, he will note that the edges of the cut draw back from the edges of the plate beneath, forming a ladder-like appearance as one moves from the middle of the cut to the outside of the plate in any direction. This is precisely what happened in Kentucky with the Cincinnati Arch.

17 These preserves came about through the diligent and dedicated work of longtime Nature Conservancy Director, Jim Aldrich. They constitute part of his significant legacy to conservation in the Commonwealth. The author had the privilege of being Chairman of the Board of Trustees for the Kentucky Chapter of the Nature Conservancy and presided over the dedication of the Sally Brown Nature Preserve. The author followed Tom Dupree in that position, surrendering it to James S. Welch, Jr. The author, for many years, has played in a bluegrass band, Funky GroundH_2O, with singer-songwriter Dan Crutcher.

18 President Andrew Jackson had a personal interest in this area of Kentucky. In 1935, he partly owned the Columbia mine near Marion in the Flourspar District of Western Kentucky. Commercial uses for flourspar did not develop until 1873 as a flux to remove impurities in iron smelting. Jackson was interested in the Galena deposits from which lead and a small amount of silver was extracted. He was familiar with this area when he purchased the land west of the Tennessee River from the Chickasaw tribe in 1818.

19 Even in modern times, Kentucky's mussel shells have found a market in commerce. In the early 1900s, buttons were made from Kentucky mussel shells. Today small beads cut from Kentucky mussel shells form the "starter" grains in cultivated oyster beds in Asia.

20 See Prehistoric Inhabitants, by Ronald R. Van Stockum, Jr. in "The New History of Shelby County, Kentucky" Shelby County Historical Society, Harmony House Publishers (2003).

21 Wildlife in Kentucky, the Reptiles, Birds and Mammals of the Commonwealth, with a Discussion of their Appearance, Habits, and Economic Importance, W.D. Funkhouser, The Kentucky Geological Survey (1925). The Preface states in part: "With the many superstitions and local beliefs regarding certain of the reptiles; with the increasing interest in birds both as to their economic importance in their relation to farm, orchard and garden and the attention which had been directed to them in the nature study work of our schools in the attempt to protect our native songbirds; with the rapid decrease of most of our wild mammals, and with the rapidly awakening desire to preserve an authentic record of the natural resources of the State, has come a demand for information regarding these animals which it has been impossible to supply."

22 Ancient Life in Kentucky, A Brief Presentation of the Paleontological succession in Kentucky Coupled With A Systematic Outline of the Archaeology of the Commonwealth, W.D. Funkhouser, Professor of Zoology, and W.S. Webb, Professor of Physics, University of Kentucky, The Kentucky Geological Survey (1928). The book contains 26 chapters, including those entitled "Extent of Prehistoric Life;" "Animals of the Ancient Sea;" "Early Land Animals;" "Neolithic Man;" "The Mound Builders;" "The Cave Dwellers;" "The Cliff Dwellers;" "The River People;" and "The Stone-Grave People."

23 The recently popular food, quinoa, is a type of goosefoot originating in Andes of South America. It was domesticated as a food source more than 3,000 years ago by the great native societies around Lake Titicaca in Bolivia.

24 Approximately 2.3 million species have been identified. For 5% of them, humans have sequenced the genome. As many as 8.7 million species may inhabit the planet and around 1,500 new ones are discovered each year. The taxonomic kingdoms and categories, taught for generations of students like the author, have been broken apart and rearranged like a scrabble board through newly discovered genetic relationships.

25 More than 900,000 species of insects have been identified worldwide, with more than five million estimated to remain undiscovered. There is plenty of opportunity to walk in the footsteps of Humboldt, Darwin, Braun, Hotchkiss, Thieret, Covell, and Jones, and engage in the "old school" science of discovery, "primary" biology.

26 North American bats are under siege from an imported pathogen, introduced in 2006 from Europe, called the "White Nose Syndrome." This disease is devastating bat populations in 26 states in the nation.

27 Kentucky's Least Wanted: The Top 20 Most Invasive Exotic Plants: Asian Bittersweet; Autumn Olive; Burning Bush; Bush Honeysuckle; Chinese Yam; Common Chickweed; Crown Vetch; Garlic Mustard; Japanese Grass; Japanese Honeysuckle; Japanese Knotweed; Kudzu; Miscanthus; Multiflora Rose; Poison Hemlock; Privet; Purple Loosestrife; Sericea Lespedeza; Tree-of-Heaven; Winter Creeper.

28 Harrison Garmin, Frank T. McFarland, E. Lucy Braun, Percy Davies, William Meijer, Arland Hotchkiss, Louis Krumholtz, Stuart Neff, Stephen Elbert, Charles Gunn, Harry Woodward, Max Medley, Charles Gunn, Julian Campbell, Ron Cicerello, Brainard Palmer-Ball, John MacGregor, David White, Jeff Sole, Richie Kessler, Bill Martin, Bill Bryant, Mary Wharton, Marc Evans, Roger Barbour, Ray Cranfill, and Ron Jones are just a sampling of Kentucky's great biologists. Many others have contributed to the knowledge of life in the Commonwealth. The activity continues today with the efforts of the Kentucky Native Plant Society.

29 Deciduous Forests of Eastern North America, E. Lucy Braun, Ph.D., 1950 (reprinted 1972), Hafner Publishing Company, New York, New York.

30 Van Stockum, R.R., Jr., 1979. Hemlock-Mixed Mesophytic Forest Communities in Southern Indiana, Western Kentucky

and Highlands, North Carolina; Ph.D. Dissertation, University of Louisville.

31 Dr. Braun described the shared dominance of the Mixed Mesophytic Forest as follows: "The Mixed Mesophytic forest climax is a community in which the dominant trees of the arboreal layer are beech (*Fagus grandifolia*), tuliptree (*Liriodendron tulipifera*), basswood (*Tilia heterophylla, T. heterophylla* var. *Michauxii, T. floridana, T. neglecta*), Sugar Maple (*Acer saccharum, A. saccharum* var. *nigrum, A. saccharum* var. *Rugellii*), Chestnut (*Castanea dentata*), Sweet Buckeye (*Aesculus octandra*), Red Oak (*Quercus borealis* var. *maxima*), White Oak (*Q. alba*), and Hemlock (*Tsuga canadensis*). In the Southern Appalachian outliers, silverbell (*Halesia monticola*) is also one of the dominants. Additional more or less abundant or local species are Birch (*Betula lutea* var. *allegheniensis, B. lenta*), Black Cherry (*Prunus serotina*), Cucumber Tree (*Magnolia acuminata*), White Ash (*Fraxinus americana*, including var. *biltmoreana*), and Red Maple (*Acer rubrum*). Sour Gum (*Nyssa sylvatica*), Black Walnut (*Juglans nigra*), and species of Hickory (especially *Carya ovata* and *C. cordiformis*) occur in a large proportion of the stands but are never abundant."

32 The mission statement of the KSNPC is: "To protect Kentucky's natural heritage by (1) identifying, acquiring, and managing natural areas that represent the best known occurrences of rare native species, natural communities, and significant natural features in a statewide nature preserves system; (2) working with others to protect biological diversity; and (3) educating Kentuckians as to the value and purpose of nature preserves and biodiversity conservation." The first director of KSNPC was Don Harker, followed by Richard Hannan, Bob McCance, and Don Dott. Previous Chairmen included Jon Rickert, Sally Brown, Hugh Archer, Judith McCandless, and Clara Wheatley. Max Medley was the first botanist, followed by Marc Evans, Deb White, and Tara Littlefield.

33 Those involved in the formation included Carl Wedekind, Sally Brown, Roger Barbour, Mary Wharton, Bruce Poundstone, Bill Bryant, William Martin, Oscar Geralds, Dot Clay, and Clara Wieland.

34 There were many significant contributors to TNC's early efforts, including Sally Brown, Tom Dupree, the Bingham family, Jim and Marianne Welch, and the Brown-Forman Corporation. TNC worked closely with the U.S. Fish and Wildlife Service, the Natural Resources Conservation Service, and the U.S. Army Corps of Engineers (on dam reoperation to improve aquatic diversity in the Green River). The organization also received support from Senator Mitch McConnell and representatives William Natcher and Hal Rogers.

35 There have been three additional Directors of the Kentucky TNC, Mike Andrews, Terry Cook and, most recently, David Phemister. Julian Campbell was the botanist for almost 20 years. Margaret Shea and Jeff Sole have been Directors of Science and Stewardship. Some of the focus of the Kentucky TNC today involves the Green River, Urban Conservation (with Chris Chandler as the first Director for Kentucky), wetlands in Western Kentucky, and the Multistate Appalachian Mountains. The current Board Chair is Kris Sirchio. The Kentucky organization has approximately thirteen employees.

36 Henry V. Heuser, Jr. is a longtime supporter of Louisville's community forest. In cooperation with the City of Louisville, Heuser created the nonprofit corporation Trees Louisville in response to Louisville's 2015 Urban Tree Canopy Assessment. Cindi Sullivan is the Executive Director.

37 Blanton Forest maintains many secrets kept by the mountain. Some are only passed on to the curious through the lore of the people who have lived there. Others have been actually witnessed. Take, for example, the "flying snakes" of Knobby Rock. Halfway up the southeastern face of Pine Mountain is a massive sandstone outcrop of rock with spectacular views of the river valley and Cumberland Mountain beyond. It is known as Knobby Rock. In 1992, when Marc Evans "rediscovered" the old growth forest, he made his way up to Knobby Rock. There, he was confronted by a dozen black snakes sunning at the high back end of the rock face. The edge dropped off precipitously into the aged forest canopy below. Racing toward them for a closer view, Marc Evans encountered an eerily strange sight.

These are Marc's words: "I was close enough to run to the edge just in time to see the strangest sight one could ever see, flying snakes! Ok, well maybe not really flying, but as I looked down from the top of the cliff I could see snakes writhing and twisting, almost looking like a dance, as they fell through the air. Could this get any stranger? Then, as the snakes hit the tree tops they simply grabbed on and wrapped themselves around the branches and slithered away, as if this was something they did all the time!"

Tom Dupree, as a boy, stayed at Camp Blanton. These are Tom Dupree's words: "At Camp Blanton, probably the first time I was there, I was invited to take a hike up to the 'jungles' (which included Knobby Rock). I was told there were caves to explore and giant trees to sit under (or hug!) and a beautiful green canopy high overhead with little or no undergrowth. I wanted to see that. ... In a short but breathless walk we were in the giant trees and a cathedral like atmosphere. The chirping of birds that were there sounded almost like they were echoes, coming from the air around us. The air was still, though there was wind in the canopy of the forest. ... For a fifteen year old boy, entering an old growth forest alone can be a little spooky. Your imagination plays tricks on you. ... I was looking for snakes because they hang out around rocks. It is not a pleasant experience to be bitten by a Rattlesnake or a Copperhead. Suddenly wham!! Something hit my cap bill, knocking it off my head and then, with a splat it hit my feet! I looked down and there was a five foot long blacksnake laying across my feet, trying desperately to get in gear and away. It only took him a second or two and he was outa-here and on the way up a tree. Of course, I nearly passed out from

fright and had to sit down for a while to get my heart rate back to something near normal. As soon as I got back to camp, I went to the camp superintendent who lived there on the grounds ... 'I told you to watch out for snakes,' he said. 'But if I told you they dropped out of the sky you wouldn't have believed me. Nobody would. They sun on the rock and when a hawk flies over they jump off that rock to hide in the woods. They don't bite. While they're falling they wiggle in a swimming motion to try to land with their underside down. They hit the ground hard, but it doesn't seem to hurt them. I bet that snake was more surprised to see you than you were to him.'" So now you know the real story of the "flying snakes" of Knobby Rock." See: KNLT.org/blog/flyingsnakes/.

38 The incorporators included Hugh Archer, Donald Harker, Jr., and Robert McCance, Jr. Tom Dupree, Mrs. W.L. Lyons Brown, Augusta Lyons, and the James Graham Brown Foundation were instrumental in support of KNLT.

39 Hugh Archer's dedication to the preservation of Kentucky's wildlands continues to secure our legacy for future generations. His contribution to conservation in Kentucky has been exceptional. Greg Abernathy is the KNLT Assistant Director; Donna Alexander, long time Program Manager; Preston Lacy, Forest Steward Director; and Angie Allman, Development Associate. KNLT has received significant support from Christy Brown, Tom Dupree, the U.S. Fish and Wildlife Service, the James Graham Brown Foundation, the Snowy Owl Foundation, and the Forecastle Foundation.

40 David Handmaker is President of the Board of Trustees and Mark K. Wourms is Executive Director.

41 During the winter, dug down more than a foot in the soil, survives the burrowing amphibian, Jefferson Salamander. It is a creature of the Northeast, extending into Northern and Central Kentucky. Bernheim Forest is just within its range. In Spring, around a sylvan pond atop the Knobs, one can study the reproductive habitats of this nocturnal salamander that hides by day under moist logs, stones, or leaf litter. During Spring, one might cordon off the perimeter of the pond with black plastic, burying open tin cans along the plastic. Wait the night in a truck and periodically check the cans. One will find the Salamander on the way to breed in the pond. Gently lift the Salamander over the plastic and send them on their way into the pond. Michael Edward Douglas, Migration and Sexual Selection in Ambystoma jeffersonianum, Canadian Journal of Zoology, 1979, 2303-2310.

42 See footnote number 3 supra. The Chairman of the Board is Dr. Richard K. Kessler, a Biologist at Campbellsville University. He recently succeeded Dr. William H. Martin of Eastern Kentucky University, whose tenure as the only other Chairman of the Fund lasted almost twenty years.

43 The Coalition includes the Bluegrass Conservancy, the Boone Conservancy, Kentucky Natural Lands Trust, Kentucky State Nature Preserves Commission, River Fields, Woods & Waters Land Trust, Bernheim Arboretum and Research Forest, Future Fund Land Trust, the Kenton Conservancy, Kentucky Waterways Alliance, Louisville and Jefferson County Environmental Trust, the Nature Conservancy, Limestone Land Trust, Clear Creek Conservation Trust, and the Shelby Area Rural Conservation Inc. Austin Musselman is Chair of Limestone Land Trust, and Louise Allen is the Executive Director. Kurt D. Mason is Chair of the Oversight Board of the Louisville and Jefferson County Environmental Trust, and Noel Rueff is the Vice Chair. Judy Petersen is the Executive Director of the Kentucky Waterways Alliance, and Gordon Garner is President of the Board. Deborah White is Executive Director of the Woods and Waters Land Trust. Board members include Chris Schimmoeller, Kay Harker, Andrew Cammack and Lee Colten. Jim Ellis is President, and Vivian Hayes, Vice President, of Shelby Area Rural Conservation, Inc. Roger Smith and Walt Reichert also serve on the Board.

44 21st Century Parks was founded in 2005 as a private nonprofit corporation currently focusing on "The Parklands of Floyds Fork," and ... "building on the visionary effort of former Lt. Governor Steve Henry and the Future Fund, Inc. ..." The Parklands includes almost 4,000 acres of lands in Jefferson County, Kentucky. Dan Jones is Chairman and Chief Executive Officer. Henry V. Heuser, Jr. is Chairman of the Board. Dr. Albert Meier is a Director of the Green River Preserve. Also note that Murray State University manages the Hancock Biological Station on Kentucky Lake.

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Kentucky's Land Snails and Their Ecological Communities, Daniel C. Dourson, 2010, Dourson Biological Consulting, Stanton, Kentucky.

All photographs are by the author with the exception of the "Winter Fox," courtesy of Cheryl Van Stockum Photography.

Indoor Air Quality and Public Health

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Human ecology is defined as the patterns and processes of interaction of humans with their environments. A predominant process impacting the global ecology has been the construction of dwellings and the increased movement to urban areas. In 1960, the percent of Americans living in urban areas was 70%, in 2014 this increased to 81%. Over the next 35 years the US population will grow by 100 million people, most of them will live in urban areas. There is an estimated 125 million homes in the U.S. They represent the largest portion of our natural resource consumption, including lumber, metals (copper, brass, steel, aluminum, tin), petroleum by- products (shingles), cement, brick and stone. Homes are the largest energy users and major consumers of water and fossil fuels. Demand for products used in the home (furniture, rugs, appliances, and household products) and to maintain our homes (chemicals, paints, HVAC systems), and waste from our homes cumulatively have imposed a larger footprint across the globe than any other activity.. In providing shelter, our homes have improved our quality of life, shaped our values, influenced life-styles, but have also posed often unseen risks to our health. This paper will explore health risks from indoor air quality.

Origins of Our Concern for Indoor Air Quality and Public Health

Polluted indoor air has been around for as long as human kind has sought shelter from the environment. The migration of humans from tropical areas to colder climates initiated the development of shelter and clothing as well as the use of fire for cooking and heating which resulted in air pollution indoors. For example, a recent report analyzing plaque from 400,000 year old human teeth demonstrated that cavemen inhaled smoke while roasting meat indoor[1]. Over time the types of indoor environments have expanded from isolated dwellings (caves and simple built structures) to aggregated dwellings (villages to urban cites) to different types of occupational (factories, offices, and mines) and agricultural environments.

In the 19th century, the development of mechanical power fostered the centralization of manufacturing and urban aggregation of the workforce. Under these conditions, housing was in short supply and large numbers of people lived together in very poor conditions. Edwin Chadwick, one of the early founders of modern public health practice described the living conditions in London: “I found the whole areas of cellars of both houses were full of night soil, to a depth of three feet, which had been permitted for years to accumulate from the overflow of the cesspools; upon being moved, the stench was intolerable, and no doubt the neighborhood must have been more or less infected by it[2].” Most of the early efforts to control indoor air pollution were focused on eliminating odors. At that time, disease was associated with odors and if odors were eliminated then so would the risk for disease. In the mid-19th century there were calls for the use of ventilation to control odors and by 1858 there was a recommendation for an air exchange rate of 25 cubic feet per minute (cfm)/person in hospitals[3].

Other actions to address indoor air quality prior to the 20th century were focused on occupational environments. These actions began with development of health and safety regulations in the late 17th century in the metal and coal mining industries in Europe and in the textile industry in the United Kingdom. The United States began developing similar legislation in the late 19th and early 20th centuries, culminating in the creation of the Occupational Safety and Health Administration (OSHA) in 1970.

Prior to 1970, the concern for indoor air quality outside of occupational environments was limited. However, several events in the 1970’s expanded the concerns about indoor air quality and health to offices and residences. The first was the oil embargo which occurred in 1973. As a result of the embargo, the cost of energy, not only for gasoline, but also for heating and cooling skyrocketed. In response to these costs, energy conservation measures were put in place to reduce the amount of outdoor air entering buildings. In existing residences, owners sealed windows to reduce the loss of heated or cooled air, and in offices building managers modified ventilation to reduce the amount of outdoor air entering a building. For new construction, developers began to design buildings to eliminate air leaks by sealing windows, increasing insulation, and using other strategies to limit the

inflow of outdoor air. These actions resulted in 'tighter' buildings that trapped pollutants generated by the building occupants, from building furnishings and construction materials, and from activities or processes being carried out in the building. The result was increased exposures to pollutants and complaints from building occupants.

A second event that increased awareness about indoor air quality was an outbreak of a respiratory illness at a hotel in Philadelphia hosting a convention of the American Legion in 1976. There were 182 cases and 29 deaths of what later became known as Legionnaires' disease[4]. The outbreak increased public concern about indoor air because of the high mortality rate and because the causative agent was not identified by the Centers of Disease Control (CDC) until five months after the outbreak[5]. The unknown nature of the illness made front page news and created a public health scare similar to the recent public responses observed over the last few years to SARS and Ebola. The causative agent, a bacterium, was eventually identified and named *Legionella pneumophila.* Although newly identified, this organism was subsequently associated with previous outbreaks. Studies of frozen specimens identified the organism as the cause of a 1965 hospital outbreak in which 81 patients developed pneumonia and 14 died and as the cause of an acute febrile illness identified in Pontiac, Michigan in 1968[6].

Other observations during this period that increased the awareness of health risk associated with indoor air included the recognition that asbestos, used for insulation, flooring and roofing in many public and private buildings (including schools and residences) posed a risk in these non-occupational environments. Also, the discovery of the presence of radon, a naturally occurring carcinogen, in homes in Boyertown, Pennsylvania raised concerns that homes in certain parts of the United States may have increased exposure to radon[7]. Thus awareness about the health effects of indoor air beyond the occupational environment became a concern of the general public and prompted a focus for increased research.

How much time do we spend indoors and what are the sources and concentration of indoor pollutants?

In order to assess the health risk associated with poor indoor air quality, studies were needed to determine the amount of time people spend indoors as well as the sources and levels of the different types of pollutants that occur indoors. The National Human Activity Pattern Survey (NHAPS) evaluated over nine thousand individuals using time activity diaries[8]. On average, the respondents spent 68.7% of their time in a residence, 5.4% in an office or factory, and 12.8% indoors at other locations such as bars and restaurants, for a total of 86.9% time spent indoors. Time in a vehicle (5.5%) was not included as time spent indoors, but if added to the indoor estimate, the total time indoors was 91.1%, a figure that is consistent from numerous time activity studies from around the world.

In another study, the EPA evaluated the amount of time spent indoors and also evaluated exposure to 20 volatile organic chemicals[9]. This estimate included time at work, in transportation, and in home environments and was approximately 22 hours per day (91.7%), with 16 of those hours in their homes. The study concluded that personal exposure to the 20 volatile organic chemicals (VOCs) exceeded the outdoor levels by 2-10 times and that indoor contaminants were often as high as or higher than outdoor contaminants. Thus, indoor exposure levels are often higher than exposure that would occur outdoors for some substances. Even considering that indoor contaminant levels are often lower than outdoor levels, cumulative exposure to low levels of contaminants can be as high or higher that those received from outdoor exposure because of the amount of time spent indoors.

While much progress has been made in identifying both the types and sources of contaminants in indoor environments (including both offices and residences), associating those exposures with specific health outcomes has been difficult. This is because of the variability of sources and exposure levels in different residential and office environments as well as the social and physiological variability between occupants in these environments. This variability makes it difficult to design and implement well controlled epidemiological studies to assess health risk.

What is the link between indoor air and health?

In evaluating the impact of indoor air on health, it is important to distinguish between workplace environments and residential environments. Workplace indoor environments include offices, factories, and schools while non-work indoor environments include residential dwellings which can be further divided into dwellings in urban and rural environments and between developed and developing countries. The following comments will focus on office and residential environments in developed countries.

OSHA and the Mine Safety and Health Administration (MSHA) have regulated factory and mining and promulgated specific standards focused on airborne contaminants for these environments. Indoor air quality for office and residential environments has not been regulated by either OSHA or the Environmental Protection Agency (EPA), but office buildings have been studied by both the EPA and the National Institutes for Occupational Safety and Health (NIOSH)[10,11]. The only organizations that have recommended indoor air quality and ventilation guidelines for offices and other non-industrial environments are the American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. (ASHRAE) through standards 62.1-2010 and 55-2010[12] and American Society for Testing and Materials (ASTM) through standard E1971–05[13]. Research on the health effects in residential environments has been limited due to the variability constraints on exposure levels and occupant characteristics mentioned previously.

School environments have been a focus of the EPA for over 20 years. In 2014, the National Center for Educations Statistics surveyed a sample of school districts and estimated that the average date of construction for the nation's schools was 1959[14].

Additionally, nearly one-fourth of the nation's schools have one or more buildings in need of extensive repair or replacement and nearly half have been reported to have problems related to indoor air quality (IAQ)[14]. The EPA has implemented a program called *IAQ Tools for Schools* which provides guidance documents and resources to help schools develop and sustain effective and comprehensive IAQ management programs, as well as other overall health and safety initiatives. Since its inception, the *IAQ Tools for Schools* guidance has been implemented successfully in numerous schools nationwide[15]. The local Jefferson County Public School District in Louisville, Kentucky has received special recognition from the federal Environmental Protection Agency (EPA) for its indoor air quality response program. In 2002 the district received an Excellence Award and in 2006 received a National Model of Sustained Excellence designation.

Types of Building Associated Illnesses

The types of health outcomes associated with indoor air have been described as Building Associated Illnesses (BAI) and are separated into two categories: Building related Illnesses (BRI) and Sick Building Syndrome (SBS). BRI is a summary term used to describe recognized diseases with a defined pathophysiology that can be attributed to specific exposures in a building. Table1 lists some examples of the specific types of BRIs that have been associated with exposure to specific indoor contaminants.

Table 1. BRI and Associated Causal Agents

ILLNESS	INDOOR EXPOSURE
1. Rhinitis, Sinusitis	Allergens, Molds, Spores
2. Infectious Disease Agents	Legionella
3. Lung Cancer	Radon, Asbestos, Environmental Tobacco Smoke
4. Asthma	House Dust Mite)
5. Hypersensitive Pneumonitis	Molds, Wood Dust
6. ODTS (Organic Dust Toxic Syndrome)	Endotoxins
7. Allergic/Irritant Contact Dermatitis	Formaldehyde, Fiberglass

Sick building syndrome (SBS) is defined as a building in which more than 20% of the occupants report adverse health effects, but for which there are no specific diagnosable diseases[16]. SBS is generally thought to be a condition of the building and not the occupants. SBS is difficult to diagnose due to the general nature of the symptoms which can be related to a variety of environmental exposures as well as psychosocial conditions that might occur in an office environment such as stress. Symptoms can include any of the following: mucus membrane irritation (which can include eye, nasal, and throat irritation), neurological symptoms including headaches and fatigue, respiratory symptoms such as shortness of breath and cough, skin symptoms including rashes, dryness and puritis, as well as chemosensory symptoms such as a distorted sense of smell (dysosmia). SBS is most often diagnosed by determining if symptoms improve upon leaving the building or after modifying the building ventilation to ensure a sufficient supply of outdoor air, and acceptable temperature and humidity levels.

BRIs are distinguished from SBS by the following characteristics. First, they have identifiable etiologies; second they are defined by specific clinical signs and symptoms related to specific exposures; third, BRIs persist outside of the workplace whereas SBS symptoms tend to go away when the occupant is away from the building; and fourth, SBS is affected by psychological factors that may affect how occupants feel both mentally and physically about their environment.

Sources and Types of Indoor Air Pollutants

Indoor air quality is being tested in Louisville through a research grant from the Institute for Aging to study the impact the home environment has on late on-set asthma by the elderly (defined as 60 years and older). To date 50 homes in the Louisville Metropolitan area have been assessed using a Home Environmental Checklist (EHC) and air quality monitors for volatile organic compounds (VOCs). The VOC monitors located both inside and outside the home, are set up to take 24-hour integrated samples which are collected in Summa© canisters. The samples are analyzed in the University of Louisville Air Toxic Lab using U.S. Environmental Protection Agency TO15 methodology.

Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are a large group of carbon-based chemicals that easily evaporate into a gas at room temperatures. VOCs in indoor air come from a number of sources including materials used in our homes, furnishings, cleaning products, personal care products and activities conducted in our homes.

Volatile Organic Compounds were detected in every home. An average of 30 different VOCs were detected (out of 84 VOCs measured), with a range of 16 to 48 different chemicals detected indoors in each home. On average 13 VOCs were above screening levels developed by Region 3 of the U.S. Environmental Protection Agency for air toxics. The screening levels were calculated to identify concentrations of air toxics that pose unacceptable health risks. The range for all homes tested was 8 to 22 different chemicals whose concentration exceeded screening levels. Table 2 lists those VOCs that were detected 90% of the time or greater, and are listed in order from most to least toxic. Some volatile organic compounds may react with ozone to produce secondary pollutants, including fine and ultrafine particles. Some of these secondary pollutants cause irritation and poor perceived air quality at concentrations that can be found in indoor air. Few individual VOC's have been studied in sufficient detail to link the levels found in residences and offices to specific health outcomes.

A primary source of indoor air pollutants, particularly in an urban area, is from outdoor air. In measuring indoor and outdoor air simultaneously, we have seen a tenfold increase in

concentrations of the same chemicals indoors verses outdoor concentrations of VOCs. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) have had since 2013 a residential ventilation standard (ASHRAE 62.2) that sets the ventilation rate at 7.5 cfm per person plus 3 cfm per 100 square feet. This means that for a tightly built 2,400-square-foot home with 3 bedrooms, the minimum airflow rate of outdoor to indoor air should be 102 cfm. In older homes and those not tightly built, the airflow rate may be significantly higher. This ventilated air comes from outside, and with it comes ambient air pollutants. This can be most clearly seen with Freon 11 and Freon 12, two chlorofluorocarbons whose manufacture has been banned since 1996. These refrigerants were banned due to their ozone depletion potential. Both have a half-life of 100 years. Measured indoors, they show consistent concentrations across the city and by age of home (presumably homes built after 1996 would never have used the chemical), with a standard deviation of 0.13, and identical concentrations indoors and outdoors. Pollutant concentrations indoors for a wide number of VOCs can be attributable to concentrations outdoors. These contributions are outside the control of the home owner.

Table 2

VOC	Detect (%)	Median Concentration (ppb)	Screening Level (ppb)	Source
Acrolein	93	1.32	0.00004	Cooking oil, herbicide
1,2,4 Trimethlybenzene	95	0.23	0.0012	Auto exhaust
m, o Xylene	97	0.77	0.01	Auto exhaust, paint, floor polish, cleaners
Benzene	97	0.26	0.01	Auto exhaust, air freshners, scatter rugs backing, scented candles
Freon 12	100	0.55	0.01	Refrigerant
Chloroform	93	0.19	0.02	Tap water, bleach, office printer
Chloromethane	100	0.73	0.09	Refrigerant
o, Xylene	95	0.26	0.1	Auto exhaust, water sealers, markers, floor polish
Freon 11	100	0.59	0.11	Refrigerant
Hexane	97	0.36	0.86	Glue, metal cleaner, paint brush cleaner
Toluene	100	1.88	5.76	Auto exhaust, synthetic fragrance, cleaners
Methyl Ethyl Ketone	97	1.13	7.36	Paint, cleaning agents, perfume
Acetone	100	16.74	56.68	Spray paint, furniture polish, nail polish remover, glue
Methyl Acetate	90	0.53	NA	Glue, paint brush cleaner, paint thinner

Although some of the measured indoor air pollutants are from ambient air concentrations, the majority of indoor air pollutants are emitted from indoor sources, including:

Fossil fuels. The most prevalent VOCs released from petroleum derivatives include benzene, toluene, ethylbenzenes and xylenes (BTEX). All of these have been routinely detected in homes in Louisville. Some of the indoor air concentrations may be attributable to ambient concentrations, but most of these can be attributable to indoor sources including the use of natural gas for heating space and water, cooking, and gas logs. Over 77% of the homes tested in Louisville used natural gas for heating and cooking. While furnaces and hot water heaters are vented, gas cook stoves and logs may not be adequately vented. In our study, only 20% of the stoves had fans to vent exhaust directly outside, however 49% of the homes rarely or never use their vent fan. The most common vent is built into a microwave oven installed above the stove which pulls air from the area of the stove up through a metal screen to trap grease and moisture, and then exhausts the air back into the room. Some of these systems have a second charcoal filter to trap VOCs, but not a single individual had ever changed this filter. In addition to BTEX, natural gas during combustion will release acrolein, acetaldehyde, formaldehyde, styrene, methyl cyclohexane, heptane, Methyl T-Butyl Ether, and 1,3 Butadiene.

Cleaning Products. Cleaning products may make up 10 to 12% of the VOCs in the home. These are released into the air as part of normal cleaning processes. Cleaning products, unlike foods, beverages, cosmetics and other personal care products, are not required by federal law to carry a list of ingredients. A key concern is the lack of disclosure of the numerous ingredients that can constitute a product's fragrance. That pine or orange or lemon-fresh scent in your favorite cleaner isn't necessarily natural. More often it's a synthetic aroma engineered by any number of more than 3,000 different chemical ingredients. Ingredients with well-established health or environmental hazards are surprisingly common. Long-term exposure to quaternary ammonium compounds, or "quats," such as benzalkonium chloride (includes Tilex, Scrubbing Bubbles, Fantastik, Pine-Sol, Formula 409, and Lysol for example), which are used as pesticides in antibacterial cleaners and as fabric softeners. Quats are known to cause asthma in previously healthy people.

Home Furnishings. Household products often will off-gas VOCs over time. These include upholstered furniture, carpets and adhesives, plastics, paints, wood stains and varnishes, plywood and pressed wood products. The predominant VOC off-gassed is formaldehyde, a known human carcinogen. Formaldehyde is commonly used today to bond

the adhesives in pressed wood products. It's found in particle board, hardwood plywood paneling and medium density fiber board used in shelving, cabinets and furniture. Medium density fiberboard has a higher adhesive-to-wood ratio than other pressed wood products; as a result, it is among the highest formaldehyde-emitting pressed wood products. There are 200 chemicals in the mixtures of gasses released by new carpets. Most notable are toluene, bromine, benzene, formaldehyde, ethyl benzene, styrene, and acetone and 4-phenylcyclohexane (4-PC), the latter two come from the latex backing used on 95 percent of carpets. The "new carpet" aroma is the odor of 4-PC off-gassing, which is an eye– and respiratory-tract irritant that may also affect the central nervous system. Carpets are made with agents using toxic synthetic chemicals including artificial dyes, stain and soil repellents, adhesives, moth proofing and flame retardants.

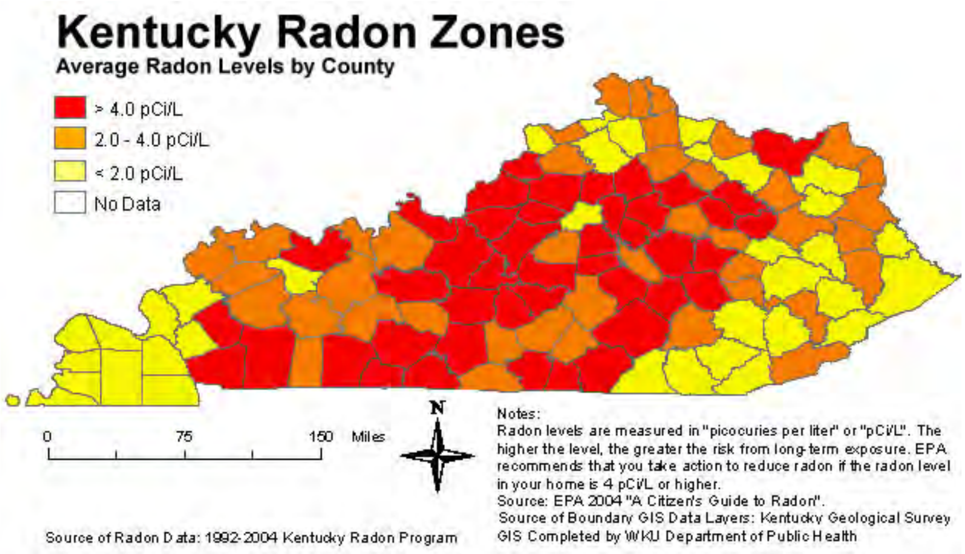

Figure 1

Radon is a radioactive gas that occurs as a decay product of uranium that is found in different types of soils. Radon can accumulate in buildings through openings in foundations, basements, and crawl spaces. The major health effect associated with exposure to radon is lung cancer. The EPA estimates that radon causes about 14,000 deaths per year in the United States, however, this number could range from 7,000 to 30,000 deaths per year[19]. The risk of lung cancer is higher for smokers exposed to radon. In areas where radon occurs, the EPA recommends that if exposure levels exceed 4 picocuries per liter of air, actions should be taken to reduce the indoor levels of the gas[19]. Figure 1 is a map of Kentucky with average radon levels per county.

Environmental Tobacco Smoke (ETS) (also called secondhand smoke)

ETS is a complex mixture of over 4,000 compounds from the burning end of a cigarette or other tobacco products or smoke exhaled by the smoker. Of the components in ETS, over 40 have been shown to cause cancer in humans or animals[23]. In a report on the health risks of ETS, the EPA concluded that ETS is responsible for approximately 3,000 lung cancer deaths each year in nonsmoking adults and causes between 150,000 and 300,000 lower respiratory tract infections in infants and children whose parents smoke[24]. The EPA also estimated that exposure to ETS increases the number of asthma episodes and severity of asthma associated symptoms in asthmatic children[25]. In addition to improving building ventilation, the most important step that can be taken to improve indoor air quality is to eliminate ETS from indoor environments. In the research study of Louisville homes, the study excludes smokers and anyone living with a smoker.

Biological Pollutants that occur indoors originate from humans and other animals, plants, insects, fungi, and microorganisms (bacteria, viruses, and protozoans). There are three categories of health effects associated with indoor exposure to bioaerosols. They are infections from microbial agents (e.g. Legionella, Tuberculosis, influenza); allergic reactions to agents of plant, fungi/mold, insect and animal origins (e.g. house dust mite, cat and dog dander, mouse urine); and toxic responses primarily due to products derived from microorganisms such as bacterial endotoxins and mold (mycotoxins). Biological pollutants can be introduced to indoor environments from outdoors by natural or mechanical ventilation. However, more frequently, they are released into the air due to favorable growth conditions in the indoor environment. For example, mold and bacteria can grow on water damaged materials (e.g. carpets, insulation, dry wall, and other building materials) as well as from improperly cleaned and maintained HVAC systems. Managing moisture is probably the single most important component for controlling the production of biological pollutants indoors.

IAQ in Developing Countries

To this point our characterization of indoor air pollution has been from the perspective of developed countries. However, the World Health Organization (WHO) has reported that indoor air pollution is a major health risk factor that accounts for 4% of the global burden of disease measured by disability adjusted life years (DALYs) lost[27] with almost 80% occurring in Africa and South East Asia[28]. Figure 2 shows an estimate of the deaths attributable to household air pollution[29].

In developing countries indoor air pollution is primarily associated with the use of traditional energy sources, such as coal and biomass (wood, dung, crop residues) for heating and cooking. When burned these fuel sources produced high levels of indoor pollution including particulates (PM10), sulfur and nitrous oxides (SOx, NOX), carbon monoxide (CO), coal combustion products,

Table 3: State of the Art of Indoor Air Quality (abstracted from reference 30)

What are the most important research findings since the first indoor environmental quality (IEQ) conference in 1978?
1. Exposure to ETS can produce adverse health effects;
2. Low ventilation rates can result in adverse health effects;
3. Emissions from biomass cook stoves are a major contributor to ill health in developing countries;
4. Sick building syndrome symptoms are real, not just psychosomatic;
5. In addition to human bioeffluents, indoor activities, materials and products can adversely affect indoor environmental quality;
6. Important infectious diseases can be transmitted by airborne routs indoors;
7. Indoor chemistry influences indoor environmental quality and health; and,
8. Exposure to particles of outdoor origin is associated with increased morbidity and mortality
What are the most important research questions for IEQ from an academic point of view?
1. How can we ensure that IEQ goals are met as energy consumption to operate buildings is reduced?
2. How much exposure to which chemicals and by which pathways occurs indoors?
3. What are the health effects of pollutants from indoor sources
4. What are the health consequences of pollutant body burdens?
5. How can measurement methods for field studies of IEQ be improved?
6. How can air cleaning, as an IEQ control technology, be improved?
7. What constitutes good IEQ?

poly aromatic hydrocarbons (PAHs) to name a few. Similar to ETS, which contains over 4,000 toxic substances, combustion by-products from traditional biomass and coal fuels contain many unidentified toxins.

The health burden in developing countries is highest among poor people living in rural areas using traditional stoves without proper ventilation. Also, women and children are at a disproportionate risk because of their gender roles and household responsibilities. A wide range of health effects have been associated with indoor cooking and heating fires, including acute respiratory tract infections, chronic obstructive lung disease, asthma, cataracts, infections agents and lung cancer. In addition to the association of the used of biomass and coal with health effects, the use of these fuels also has implications for household safety and the allocation and use of the time of household members, especially women.

Progress in Indoor Environmental (Air) Quality Research

One of the first indoor environmental quality research conferences was held in Copenhagen in 1978. Since that conference the number of researchers focusing on indoor environmental quality has grown substantially as has the number of publications and conferences. In 2010, a group of researchers convened to assess the status of indoor air research and published the results of their assessment in the journal Indoor Air (30). Among the questions addressed were: "What are the most important research findings since the first IEQ conference in 1978?" and "What are the most important research questions in IEQ from an academic point of view?" Other questions asked by this paper were, "What does society believe are the most important research questions…" and "Are there topics for which we can say, 'No more research is needed?".

Table 3 summarizes the responses to the first two questions. Of the eight findings for the first question only the topic "Indoor chemistry influences indoor environmental quality and health" was not previously discussed in this paper. Numerous studies have shown that reactive chemicals, such as ozone, can alter the chemical composition of indoor air resulting in more toxic reactants. As an example, the reaction between ozone and cleaning products produces both gas and condensed phase oxidation products that can be respiratory irritants[30]. Much more research needs to be done on indoor air chemistry to determine the impacts on health.

The responses regarding the second question suggest more in depth research is needed for many of the responses for the first question. As one example consider the second response to question two (Table 2): "How much exposure to which chemicals and by which pathways occurs indoors?" This implies that additional research is needed to characterize the types, magnitude, and pathways by which chemical exposure occurs indoors in order to adequately evaluate the health effects which are the focus of the 3rd and 4th responses.

Conclusions

Overall much progress has been made in understanding and characterizing the sources of indoor air pollutants and their associated health effects in offices and residences. While much research remains to be done in areas such as the impact of mixtures of indoor pollutants on health and the role of indoor chemical reactions on the formation and toxicity of indoor pollutants, effective strategies have been developed to mitigate the impact of indoor air pollution on health. These include strategies to reduce

or eliminate the release of pollutants from indoor materials, the development and use of low emission building materials, and recommended work or activity practices that reduce the release of pollutants indoors. These strategies when coupled with optimum ventilation, filtration, and moisture control provide effective tools to reduce the impact of indoor air pollution on health.

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GROWING A LOCAL FOOD ECONOMY-FROM THE GROUND UP

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There is much attention now focused on growing a local food economy. Louisville and Kentucky are front and center on this issue. Like many states, Kentucky has a rich agricultural heritage. In recent years, the national issue of reducing the marketing of tobacco products and phasing out price supports and related subsidies for tobacco, long a significant crop in Kentucky, has caused a shift of attention at the state level to alternative crops and enhancing the availability and sale of more local foods. The national tobacco settlement program has infused the state with substantial monies to promote new agricultural ventures and infrastructure. Louisville is garnering increasing attention regionally, nationally and even internationally for its outstanding food offerings, in particular, a large number of world class restaurants which require high quality food ingredients. This article will explore issues related to our local food economy, developing certain kinds of local food businesses and resources and assistance helpful, if not necessary, for their success. The authors have each developed local food businesses over the past several years. One business is a value-added specialty food manufacturing business (horseradish) and the other a home delivery business specializing in dairy products and other local foods.

First, we will provide more background about each of the local food businesses begun by the authors with references to some of the challenges they have faced. Then, the article will explore in more detail some of the opportunities and barriers to grow our local food economy further.

ARNO ENTERPRISES, LLC (Hot 2 Trot Kentucky Horseradish Sauce)[1] A Case Study

In 2010, after growing horseradish in their home garden for about 30 years and making it into a much-loved sauce for family and friends, and after retiring from their main careers, the owners decided to start a company to grow, make and sell the sauce as a commercial product. The initial goals were simple--provide a unique and tasty food product to the local community, do something different than they had been doing, have some fun and make a reasonable return on invested capital. In general, all goals have been realized.

The specialty food company (Arno Enterprises, LLC) is, we think, the state's largest manufacturer of horseradish sauces and is a vertically-integrated venture. In this case, that means that the company grows the horseradish, harvests it, processes it into the various value-added products and markets and sells the products both wholesale and retail.

A key initial decision was to try to grow the horseradish for the products. A supplier was found of the preferred root type and about a quarter acre of farmland was rented on a nearby horse farm in Shelby County. (In 2013, the crop was switched to Foxhollow Farm in Oldham County, Kentucky). It was decided to let the crop grow for two years for larger roots (horseradish overwinters nicely) and to allow time for the steps to get the other elements of the business in place. Additional key elements included determining who would make the products, where the products would be made and how to ensure that the products were made with a careful eye toward food safety issues. After evaluating these issues and options, it was decided the owners would make the products in a local, state-approved commercial kitchen. They also enlisted the services of the University of Kentucky Food System Innovation Center (UK FSIC) to assist on food safety and other issues. [2]

With key elements in place, Hot 2 Trot began selling its sauce at the Douglass Loop Farmers Market in Louisville in January 2012 and has continued selling there through the 2015 season.[3] Additionally, it has added several retail outlets, in Louisville, Berea, Shelbyville and Florence, Kentucky and has done other farmers markets and specialty events. In addition, the Bristol Bar and Grille, which has been very supportive of local foods and farmers for many years, has used the company's products in several of its prominent promotions of local foods.[4]

The company and its products participate in the Kentucky Department of Agriculture's marketing and promotional campaign called Kentucky Proud and the owners are confident that the use of this branding label has benefited sales of its products. [5]

The company now has three featured products. Its original sauce is a traditional mayonnaise-based sauce which can be

used on meats, sandwiches and in dishes like mash potatoes and devilled eggs. Two other products have also proven successful—Straight Up Horseradish which is fresh grated horseradish with vinegar and its very unique Blackberry Horseradish sauce. From 2012 through 2014, the original sauce was the primary product for the retail outlets but the company began selling the blackberry at retail outlets in 2015. A key issue for retailers is the shelf life of a product. The original sauce has a 5-month "better if used by" date (from the date of production) and the blackberry sauce has a 3-month date.

To date, the company has relied almost solely on word of mouth and Facebook for its marketing. Free samples and recipes are also handed out and used for marketing. In addition the company donates promotional gift baskets of horseradish for charity events. The company has also received valuable marketing advice and services from the UK FSIC. This agency provides such services as shelf-stability studies, food safety classes, marketing advice, food preparation guidance and taste panels and several other very important services. The FSIC has been funded by the tobacco settlement monies and so does not have a long-term sustainable source of funding. That issue needs to be addressed as the FSIC provides valuable services to the food community.

A particularly helpful marketing program offered by the UK FSIC is its MartketReady training which conveys helpful and important information to food producers about what buyers are looking for and how to connect with them. It also has an especially useful program that matches buyers and sellers. Arno has obtained several successful leads though that program.

Current opportunities for the growth of the company could come from additional product lines, increasing the number of sales outlets, broadening the geographic scope of the sales market, increasing the margin by further controlling costs and/or increasing unit prices and more advertising. Challenges include finding effective means to reduce costs and maintain price points that work in the various marketplaces where the products are sold. The company considers its successes to include having developed multiple products that have substantial customer appreciation, developing a significant and positive network of connections with people, organizations and agencies within the local food community, and having built a generally successful small business.

But the successes have not been easy and the path for the company has included numerous barriers and challenges which will be discussed in more detail below within the context of enabling more people to enter this vibrant and growing arena.

EHRLER'S MICRO DAIRY-A Case Study- a Retailer of Artisan Dairy Products and Other Local Foods

Started in 2012, Ehrler's Micro Dairy engaged in the retail sale of artisan dairy products and other local foods. The owner's vision was to resurrect an old local foods brand - his family operated a prominent local dairy for more than 100 years - and serve as a link between local food producers and consumers in the Louisville marketplace. The company did not produce its own products, but instead sold approximately 75 products produced by a dozen local farmers and food artisans. It focused on an old-fashioned market niche - home delivery of low temperature pasteurized, non-homogenized (cream top) milk in returnable glass bottles. But it updated the concept by offering a range of other local foods and providing a web-based ordering system allowing customers to set up a base order which could be customized on a weekly basis depending on their needs. Most deliveries were made between midnight and 7 a.m., so customers, upon awakening, would find their orders on their porches in insulated coolers. Some customers remarked that home delivery of milk was so traditional that it was "edgy."

Customer density on delivery routes was a key factor to success of the delivery business. To achieve the required density, the owner "selected" his customers by conducting a door to door solicitation campaign on selected streets. The owner not only distributed marketing materials, but also offered a free bottle of milk to potential customers. When a new customer on a previously unserved street signed up for delivery on the company website, the owner would go door to door in an effort to recruit additional customers on that street. Ehrler's commenced operation in May 2012 with no pre-signed customers. After one Saturday of door to door solicitation, it picked up approximately 10 customers. At peak the company had almost 350 active customers with approximately 1100 monthly orders. Approximately 80% of its sales consisted of dairy products, with the remainder consisting of eggs, baked goods, jams, honey, and spring water. Its core delivery areas were Cherokee Triangle, the Highlands, Crescent Hill, and St. Matthews. The company also sold dairy products on weekends at two farmers markets in the Highlands and St. Matthews neighborhoods.

Non-producer retailers selling local foods exclusively occupy an "exciting," but challenging market niche. Because most local foods are produced on a "micro" scale, they generally cannot compete in the marketplace on a price basis alone. They generally compete on product freshness and quality. Through home delivery, Ehrler's was able to offer the added dimension of convenience. Although the company was not a producer of local foods, it operated on a small enough scale to provide an effective link between its customers and producers. As the company grew, it encountered the typical challenges of a local food retailer: consistency of supply, consistency of quality, and availability of specific products to meet specific demands of its customer base. A national supermarket chain which includes local products in its product offerings can offer substitute products when the local production of eggs or butter decreases in the heat of the summer season. On the other hand, a retailer which markets local foods exclusively may simply lose sales when temporary gaps develop in its more limited range of product offerings. Although it initially offered only products from Kentucky producers, the company eventually added some Indiana and Ohio products when a particular product was unavailable from Kentucky artisan

producers or not consistently available. Having gained insight into the marketplace for local dairy products, the owner ended the delivery service in 2015 to concentrate on developing his own small dairy processing plant for artisan dairy products.

The Definition of Local Foods

There is no generally agreed upon definition of "local food." The distance between producer and consumer would seem to be a key factor. A common rule of thumb is that local food must be produced within a 100-mile radius of its point of consumption. But that definition is far from universal. Some national supermarket chains have local food procurement programs aimed at producers located within transport times of seven hours to one day from their stores. One farmers market in Louisville accepts vendors located anywhere in Kentucky. Another local farmers market accepts vendors located in Kentucky or southern Indiana. A 2012 study commissioned by Seed Capital Kentucky and Louisville Metro Government found that the largest percentage of commercial food buyers defined local foods as that grown less than 150 miles away, with lesser percentages identifying 100 miles or even 50 miles as the appropriate delineation.[6] A 2008 study commissioned by Louisville Metro Government to assess the potential for increasing locally grown and produced food focused on producers in the 23-county "Louisville region," within approximately 50 miles of the city.[7] Which of the following should be considered a producer of local food for Louisville: a small family-owned on-farm dairy processing plant located 140 miles away in Russellville, Kentucky or a small, off-farm artisan dairy plant located 120 miles away near Indianapolis, Indiana? What if a Kentucky processing plant produces yogurt made from Kentucky milk and Michigan berries? It seems that any distance limitation associated with "local food" is largely shaped by the objectives and operational realities of the party defining the term.

But the term "local food" certainly reflects additional nuance beyond the mere proximity of the producer to the consumer. It suggests a direct connection between producer and consumer which is altogether absent from a sterile transaction such as purchase of a store brand product in a chain supermarket. The local food movement exhorts consumers to "know where your food comes from," or even to "know your farmer." To many consumers, the term local food suggests food produced by a small farmer or food artisan on a human scale, rather than food produced by a manufacturer on an industrial scale. Consumers expect local food to be fresher and less processed than mass-produced food. For many, local food provides an important link between people and place. It has a connotation of shared traditions and common interests, with local farmers and food artisans contributing to the vibrancy and uniqueness of the community and local dollars spent on food remaining in the local economy. To continue the previous illustration, a large dairy processing plant located in Louisville, owned by a multi-billion dollar corporation and processing milk from a regional milkshed, might arguably meet the distance requirement necessary to be considered a local food producer for Louisville. It would certainly serve local economic interests in terms of jobs provided to the community. However, many consumers would not consider it to be a local food producer because, unlike a farmer, a large corporation is inherently unknowable and it is impossible to discern the origin of products produced on an industrial scale. Perhaps the term local food, like beauty, must be left to the eye of the beholder. Another key question is what is the demand for local food?

Demand for Local Foods

In 2012, Seed Capital Kentucky and Louisville Metro Government commissioned "*The Louisville Local Food Demand Analysis*," a comprehensive analysis of the demand for local foods in Louisville and Jefferson County.[8] Louisville residents spend approximately $2 billion each year on food, both in and away from home. Based on focus groups and interviews with key stakeholders and surveys of consumers and commercial buyers, the study found significant unmet demand for local foods. The study found that 72% of Louisville residents and 63% of commercial buyers purchased commercial foods over the span of a year. The surveys indicated that 95% of Louisville consumers perceived local food to be more flavorful and of generally equal or superior quality to non-local food. Commercial buyers identified support for local businesses and the economy, support for local farmers and product freshness as the top reasons for purchase of local foods. The study found that Louisville residents spent $100 million on local foods, but were interested in spending an additional $158 million, for a total demand of $258 million. Commercial buyers spent $214 million on local foods, but were interested in spending an additional $139 million, for a total demand of $353 million. While a significant number of local food producers have entered the Louisville market since 2012, it appears that there is the potential for a substantial additional expansion in production of local foods. Certainly, this conclusion is supported by the experience and observations of the authors.

However, fully realizing the potential for a more robust local food economy requires many elements to come together successfully. In our community and state, some of these elements exist and some are not yet fully in place. With missing elements, a community will not achieve its full potential.

Distribution of Local Foods

Local foods are sold through a variety of channels. Traditionally, some farmers "by-passed the middle man" and made direct sales to the consumer through on-farm stores, "U pick" operations, and road-side stands. The rise of the internet and advent of "electronic storefronts" has equipped local food producers with an important new tool to make direct sales. Farmers markets have also become a significant venue for the sale of local foods. Louisville now has approximately 20 farmers markets, with at least one market open every day of the week. In recent years, Community Supported Agriculture (CSA) operations – which generally involve a consumer signing up for a share of a farmer's seasonal production – have become increasingly popular. As large retail chains have developed special programs aimed at local

food producers, local foods have become increasingly available at "big box" grocery stores. Metro Louisville's Healthy Hometown initiative promotes the sale of healthy local foods in stores located in the city's "food deserts." In response to the growing demand for local foods, existing food distributors have added local foods to their product lines and new distributors focusing on local foods have been established. Prominent restaurants increasingly focus on expanding their local food menu offerings. New sales outlets continue to arise with the revival of old concepts such as home delivery and the birth of new concepts such as food trucks and temporary "pop-up" storefronts.

Barriers to Local Foods and Potential Solutions

Local food producers, who are often small-scale farmers, find it challenging to produce cost-competitive products, meet periodic demand for high production volumes, ensure consistency in quality and deliveries, and provide products on a year-round basis.[9] These barriers are borne out by the 2012 demand analysis for Louisville. While most local foods purchasers were willing to pay a higher price for local foods, higher prices was the largest single barrier to both consumers and commercial buyers. In addition, commercial buyers cited lack of reliable supply as a concern.

A major impediment to growing a stronger local food economy is the lack of a cost-effective supply chain that provides for distribution of local food products throughout at least the larger population centers of the state. Lacking economies of scale, most small food producers operate at a very thin margin of profitability. While it is generally viable for small producers to sell to retailers at wholesale prices to allow a standard retail markup (generally at least 25-35%), their margins are usually too narrow to permit sales to a distributor who would demand an additional markup. Consequently, the existing food distribution supply chain is generally unavailable to small local food producers. There is a dire need for a distribution system providing small producers with cost effective access to a wider market and retailers with the dependable supply required for sales on a commercial scale. If the existing food distribution networks are not adapted to the small local foods producer, many small producers will never become viable and the availability of local foods in the marketplace will be constrained.

There have been a number of major efforts to improve the supply chain for local foods. While most CSAs are offered by a single farm with limited product availability, Grasshoppers Distribution purchased its products from a number of farmers and producers. Serving as an aggregator of products, Grasshoppers had the capacity to reach a larger market than would otherwise be feasible for an individual farmer or producer with limited and fluctuating product supplies. More recently, Louisville Metro, Seed Capital Kentucky, and other partners announced the West Louisville Foodport.[10] The Foodport will serve as a "food hub" bringing together farmers and a mix of industrial processor tenants using a variety of local food products. The Foodport will essentially function as a farmers market on a commercial scale. In 2008 Louisville Metro commissioned "*Building Louisville's Local Food Economy: Strategies for increasing Kentucky farm income through expanded food sales in Louisville*." One of the key recommendations was development of infrastructure such as cold storage to allow aggregation of local products and better integration into the existing supply chain.[11] Continued evolution of the existing supply chain will be critical for the sustained growth of local foods. Key entities such as the Kentucky Department of Agriculture, via its Kentucky Proud program, should take the lead on addressing necessary supply chain refinements on a state-wide basis.

The authors have had substantial exposure to the arena of government regulation through long professional careers that pre-dated their involvement in local foods. But, even with such experience, determining all the necessary federal, state and local government requirements in areas ranging from food safety to transportation was not easy. In fact, it was quite challenging.

Additionally, neither set of authors/owners had previous experience starting a business from the ground up-pun intended. What both sets of business owners have encountered is insufficient local and state resources devoted to assisting start-up food ventures. There is some assistance but there is not enough. And this dearth of assistance constitutes a major barrier of entry for others who may be considering such pursuits. Anecdotally, the authors believe there are many, many people in our local area who would like to pursue various food-related ventures but do not know where to start.

The University of Kentucky, with its large and historic role in aiding Kentucky agriculture is clearly well-positioned to provide a major service to new food entrepreneurs by expanding its programs and services for this potential growth area. The University's excellent County Cooperative Extension programs also serve as valuable resources for new farmers and producers and its services need to be maintained and even enhanced.

The Kentucky Department of Agriculture should have a substantial role to play in cultivating new food businesses but its major emphasis seems to be on helping existing farmers and the established agricultural industry. This is obviously important, but new food entrepreneurs would benefit by greater attention from the Department. Its Kentucky Proud marketing program does aid small food ventures but there is much room for improvement in that program. There seems to be a tendency for the Department to put much of its attention on the largest of the manufacturers and farmers.

At least two significant issues/problems exist at the state level in providing better coordination and delivery of services to the budding food entrepreneur. First, the governmental infrastructure for agriculture and food-related issues is very decentralized—if not fractured—and there needs to be much more centralized coordination and planning around these issues. Perhaps the Governor's Office of Agricultural Policy[12] could play this role. Second, there is opportunity for improvement of the regulatory

framework for food producers and farmers. From confusing and inconsistent regulations (for example the definition of a statewide mobile food establishment) to unnecessary paperwork (for example for farmer's market vendors) there are ample opportunities to streamline and make the regulatory framework more efficient, understandable and helpful. This could be an area where a stakeholder group of interested parties could provide the applicable agencies some useful feedback and suggestions.

In starting a food business, there is, of course, the business aspect. But there is also a specialized food component. Some of the business issues are generic to any business—what legal entity to use and details about creating a company, where to bank, etc. For some of this, a neophyte can turn to the traditional entities like a local chamber of commerce, or the Small Business Administration. But other issues are specific to a food business and require more specialized assistance—how to decide what products or services to be offered, if land is needed where to find it economically, if it is a value-added product, do you make it yourself or get someone to make it for you (a co-packer)? And the list goes on and on.

For all farmers, and those food producers who seek to grow their own products, access to affordable and suitably farmable land is necessary. While there is still some farmland in the Louisville area, it is expensive and there is not an easy path to actually get on and use this farmland. However, one example of a great model which addresses this need is the third generation, family-owned Foxhollow Farm in Oldham County, Kentucky which makes some of its farmland and farm-related services affordably available for its farmer partners.[13] The Foxhollow model is one that could and should be replicated by other farm owners in the region.

To assist potential new food market entrants, another critical need is a local, one-stop incubator that can provide a wide range of assistance, information and services to start-up food ventures. There are excellent models for such incubators. In particular, since 2010, New York City has invested more than $2.5 million in three culinary incubators that have played very important roles in the creation and development of scores of new food ventures helping them with such services as access to reasonably-priced commercial kitchens, marketing, insurance and identifying markets.[14]

Access to affordable and adequate capital can be a significant barrier for new food businesses. While some second-career entrepreneurs may be able to self-capitalize their small business, many businesses lack access to traditional types of lenders such as banks and venture capitalists. Fortunately, there are now a number of capital sources created for such entrepreneurs, some of them specifically geared to food entrepreneurs such as Seed Capital Kentucky. Plus, there are a number of well-known and credible crowd-sourced avenues to seek funding from the general population. Local and state officials should help market these sources to potential and existing food businesses so that they may be able to scale their businesses as necessary and achieve the growth potential both for the companies and the local economy.[15]

And, as to markets for vendors to sell their products, while Louisville has come a long way in the last five years or so with farmers markets, there is still untapped potential to develop an even more vibrant and robust market infrastructure. Most of Louisville's farmers markets are seasonal, which leaves a significant gap for selling local foods in the cold weather months. Although the need for a seven day a week, year round indoor farmers market in the downtown area was identified in the 2008 study commissioned by Louisville Metro, little progress has been made toward that goal. Three very successful regional markets serve as great examples of robust year-round markets that aggregate enough vendors to attract enormous throngs of customers. Both Nashville[16] and Chattanooga[17] have markets that demonstrate the substantial punch and enhanced quality of life that such a market can bring to a local community. In Cincinnati, the Findlay Market[18] has been an incredibly successful large multi-vendor market for many years.

In New York, the well-known chef and global foodie, Anthony Bourdain, is developing a new major 155,000 square foot, year-round indoor food market that will feature over 100 retail and wholesale food vendors such as fishmongers, butchers, bakers, and other food artisans with at least one full-sized restaurant and many international food vendors.[19] In some respects the West Louisville FoodPort resembles this Bourdain project, but the local project is still in the very early stages and appears to be of much more limited scope than the New York project. But it promises to play a very important role in boosting the local food economy if it is successful.

Perhaps a citywide task force or stakeholder group could be assembled from interested persons-both producers and customers-to examine new market opportunities for Louisville and the surrounding area.

Conclusion

It is clear that Louisville already has an expanding local food economy with substantial demand for more local food products. A vibrant local food economy adds jobs, quality of life and improved public health to a community. There are significant numbers of people who want to participate in this economy as farmers, producers, sellers, and purchasers. So, unquestionably, there are great opportunities. But, while there are also barriers to further progress, there are great examples and ideas on how to knock down these barriers to let more participate in this exciting opportunity.

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